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Banksia woodland resilience to groundwater drawdown on the Gnangara Mound

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Banksia Woodland Resilience to Groundwater Drawdown on the Gnangara Mound.

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USE OF THESIS

The Use of Thesis statement is not included in this version of the thesis.

Abstract

Water is considered to be the major limiting resource to plant growth and survival in regions with a Mediterranean-type climate, particularly during dry summer periods when low water potentials develop (Poole et al., 1981; Miller et al., 1983-84; Mooney and Miller, 1985; Stock et al., 1992). The Swan Coastal Plain is situated within this climatic region, and interactions between the climate, soil and geology has an important bearing on the water requirements of the associated *Banksia* woodlands (Dodd and Heddle, 1989).

The assessment of the condition of any vegetative community, and in this case, the resilience of *Banksia* woodlands to groundwater drawdown, is dependent upon a complete understanding of the factors influencing that particular plant community (Sharma, 1989). The main determinates influencing the location of different plant communities on the Gnangara Mound are the underlying site conditions and depth to groundwater, both of which fluctuate on a seasonal basis. For example, *Banksia ilicifolia* can be found in the middle to lower slopes and depressions where depth to groundwater is relatively low, and other species such as *Banksia attenuata* and *Banksia menziesii* are found across a topographical gradient as they can tolerate a greater range in conditions (Allen, 1981).

The aim of this thesis is to assess the resilience of *Banksia* woodlands to sudden groundwater decline events, by incorporating the main results obtained from the three specific aims in the project. These were:

1. Identify and describe the hydrological and climatic regimes associated with sudden decline events and recovery of a *Banksia* woodland community.

2. Examine the floristic changes and recovery in a *Banksia* woodland community impacted by a sudden groundwater decline event.

3. Assess the resilience of *Banksia* woodland communities to sudden groundwater decline episodes.

The Bassendean dune system forms a part of the northern Swan Coastal Plain, under which lies a large shallow unconfined aquifer, the Gnangara Groundwater Mound. Groundwater and soil moisture levels have been gradually decreasing in most areas of the Gnangara Mound since the 1970s, as a combined result of a number of years of below average rainfall and increased groundwater abstraction (Davison, 1995). The Gnangara Mound is the largest and most important shallow underground water resource in the Perth region and it supplies substantial amounts of water to meet Perth's current water demands, and is, therefore, a vital resource to Perth and the surrounding regions (Heddle, 1986).

In conjunction with this use, the Gnangara Mound also represents a significant water resource to native phreatophytic (groundwater dependent) vegetation. To safeguard terrestrial vegetation, groundwater levels must be maintained to allow plants access to water which is required for their growth and continued existence. In many areas throughout the Gnangara Mound, studies by Havel and Mattiske have indicated that watertable drawdown has a high potential to impact on phreatophytic vegetation. A lowering of the watertable level and the climatic changes over the last 30 years has resulted in measured changes in community composition to more drought tolerant species. This was observed at the long-term monitored sites that were examined as part of this study (Neaves and Yeal Swamp). The survival of groundwater dependent vegetation to drawdown depends on a species' capacity to adjust to reduced water availability.

In conclusion, the research documented in this thesis has used both experimental data and data derived from the existing Waters and Rivers Commission's long-term vegetation database. From the results, it can be concluded that on the whole, *Banksia* woodland communities are resilient to large-scale drawdown events and will recover to an equivalent state if time permits.

DECLARATION

I certify that this thesis does not incorporate, without acknowledgement, any material previously submitted for a degree or diploma in any institution of higher education; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where reference is made in the text.

Signature...[redacted]

Date...24-8-2004.....

Acknowledgements

I would firstly like to thank God for the opportunity he has given me to complete my Degree and Honours Programme in Environmental Science.

I would like to thank my wife and children for their support and understanding over the past years and for the encouragement they gave me, which has allowed me to achieve the goals I set out to achieve. Thanks to my extended family for their encouragement and to Kevin and Esther who always believed in me.

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Chapter 1

Introduction

1.1 The Gnangara Mound

Western Australia is the second driest state in the world's driest continent and fresh water is one of our most important resources. These resources are a vital ingredient dictating our way of life economically, socially and environmentally. They support ecosystems and provide water for drinking, livestock, irrigation, industry and domestic gardens. Our water resources exist in streams, rivers, lakes, wetlands and groundwater aquifers. One of the largest and most important aquifers in the state is the Gnangara Mound, located north of Perth (Waters and Rivers Commission, 1997).

The Gnangara Mound covers an area of about 2,140 km^2, extending from Gingin Brook and Moore River in the north to the Darling Scarp in the east, the Swan River in the South and the Indian Ocean to the west. It is a shallow underground, unconfined sand aquifer, formed by sediments deposited over the last 2 million years, with a saturated thickness of up to 70m (Water Authority of Western Australia, 1992).

Large amounts of easily accessible fresh groundwater are located on the Gnangara Mound. As the groundwater table is often close to the surface, the aquifer supports a variety of significant environmental features such as wetlands, shallow cave streams, springs, seepages and native vegetation dependent on groundwater. The Gnangara Mound also recharges the deeper confined aquifers found in the area, the Leederville and Yarragadee aquifers (Waters and Rivers Commission, 1997). Large stands of phreatophytic *Banksia* woodlands are scattered throughout the area and are reliant on maintained groundwater levels. The vegetation characteristics of the Gnangara Mound are strongly interrelated with landforms, soil type, soil moisture, and most importantly, groundwater availability (McArther, 1986). The dominant form of vegetation in the area is open *Banksia* woodland. Many of these areas of *Banksia* woodland have been cleared for urban and rural development, which is why remnants, such as those on the Gnangara Mound, are considered to be regionally significant (Water Authority of Western Australia, 1995).

An estimated 18,800,000,000 kL of water is stored in the shallow aquifer and the annual recharge is estimated to reach up to 557,000,000 kL. Perth's groundwater resources are extensively used with more than 80,000 shallow bores pumping as much as 220,000,000 kL of groundwater per year (Western Australian Planning Commission and Water and Rivers Commission, 1999). Most bores provide water for maintaining domestic gardens, irrigation for larger parks, recreational ovals and golf courses. Other bores provide water for larger irrigation projects such as market gardens, industrial purposes and drinking water supplies for Perth. Groundwater supplies around 127,000,000 kL or 40% of Perth's drinking water. With Perth's continued growth, this is expected to expand to 50% over the next 15 years (Western Australian Planning Commission and Water and Rivers Commission, 1999).

As Perth grows, maintenance of our lifestyle and environment will depend on the availability of large quantities of high quality groundwater. If our groundwater resources become contaminated or depleted, the range of activities this water can be used for will be reduced (Water Authority of Western Australia, 1995; Western Australian Planning Commission and Water and Rivers Commission, 1999).

All ecosystems require water to maintain their ecological processes and associated communities of plants and animals. Throughout Western Australia, increasing pressure from consumptive uses has led to the review of the role that groundwater plays in controlling the health of major ecosystems (Froend, Farrell, Wilkins, Wilson and McComb, 1993). To ensure the continued health of these ecosystems, the respective needs of phreatophytic ecosystems, need to be formally recognised and provided for. Determining water needs (water requirements) for an ecosystem involves identifying those aspects of the natural water regime that are most important for maintaining key ecosystem features and processes (Froend and Zencich, 2001).

Broadly speaking, the *Banksia* woodlands of the Gnangara Mound are floristically representative of the State's South-Western flora, since their dominant families and genera are also the dominant taxa of the South-West (Dodd and Griffin, 1989; Farrington, Watson, Bartle and Greenwood, 1990). However, despite their simple structure and seemingly uniform appearance, *Banksia* woodlands are floristically rich and taxonomically diverse. Floristically, they appear to have close affinities to the kwongan of regions north of the Swan Coastal Plain (Richardson and Kruger, 1990).

The woodlands of the Gnangara Mound do exhibit a high degree of variability through close inspection, indicating a response by the component species to a range of environmental variables, of which edaphic factors are the most important. *Banksia* woodlands can be divided into a number of floristic types based on their understorey characteristics, as little variation is usually observable in canopy species. The characteristics of these categories are related to topography, soil type, moisture status and geographical location. The degree of floristic variation found in *Banksia* woodlands has significant implications for conservation, since adequate conservation requires that the range of variation should be represented in reserves (Dawson and Pate, 1996; Dodd and Griffin, 1989).

The soils on which *Banksia* woodlands typically occur are deep, leached, quartz sands of extremely low water holding capacity (Richardson and Kruger, 1990). The edaphic factors mentioned above, in combination with low rainfall, high temperatures and high evaporation rates during summer, are conductive to the development of severe water stress among plant species situated in these conditions (Marchant, Wheleer, Rye, Bennet, Lander, and Macfarlane, 1987).

Resilience is a concept that has been presented as a means of defining how an ecosystem copes with change. This concept is critical to the way in which complete ecosystems adapt to environmental changes and was introduced to ecology by Holling (1973) as a way to comprehend the non-linear relationships observed in ecosystems. The term resilience has been defined by Holling (1996) as the ability of a plant community to return to a stable state following a perturbation. This definition of resilience examines the changes that occur in a system following a disturbance event, as a way of identifying the degree of plant community resilience. If a community returns to a similar stable state that is representative of what existed before such an event, then the community can be classified as resilient (Gunderson, Holling, Prictchard and Peterson, 2002).

As a way of identifying the floristical changes occurring across the Gnangara Mound, the Waters and Rivers Commission conducts a monitoring program, of both hydrology and vegetation, related to its groundwater management responsibilities. The hydrological monitoring program situated on the Gnangara Mound includes a network of approximately seven hundred groundwater observation bores. A number of long-term vegetation monitoring transects were also established, with the aim of assessing the changes in plant community composition of fifteen transects to groundwater fluctuations (Groom, Froend, Mattiske and Gurner, 2000b). Previous studies on the effects of groundwater changes on phreatophytic vegetation indicate both drawdown and groundwater decline effect *Banksia* woodland vegetation, however, little is known about the resilience of such systems to drawdown.

Previous monitoring of the vegetation on the Gnangara Mound suggests a change in the *Banksia* woodland communities towards the xeric end of the floristic continuum is occurring (Mattiske and Associates, 1995). It is the gradual decreasing trend in hydrology across the Gnangara Mound, combined with reduced recharge due to low rainfall and higher temperatures, abstraction and the pressures of other groundwater users (eg; pine plantations) that have attributed to the this push in floristics to species tolerant of drier conditions.

The impact and consequence of groundwater drawdown on phreatophytic vegetation ranges from gradual changes in community composition over decades, to sudden and extensive vegetation deaths (Groom, Froend and Mattiske, 2000a). Gradual changes in *Banksia* woodlands due to reduced soil water availability occur over a relatively long period of time and this change is also repeated in species composition and community structure (Froend et al 2000a; Froend and Zencich, 2001; Groom, Froend, Mattiske and Gurner, 2000b). Overstorey species that cannot tolerate long periods of reduced soil water availability are slowly dying out and being replaced by more drought-tolerant species (Western Australian Planning Commission and Water and Rivers Commission, 1999).

A more acute and noticeable response to reduced soil water availability is observable in events that cause sudden and extensive vegetation deaths. This form of response occurs when rapid groundwater drawdown is combined with low rainfall recharge rates. An example of this response is summer of 1990/1991 event where up to 80% of all *Banksia* trees and 60-70% of the understorey died within the vicinity of P50, a production bore in the Pinjar borefield (Groom, Froend and Mattiske, 2000a). Although the vegetation is recovering, little is known about the possible changes that have occurred to vegetation characteristics, i.e. whether the recovered vegetation characteristics are significantly different in composition, function and groundwater requirements from pre-drawdown conditions (Groom, Froend, Mattiske and Koch, 2000c; Gunderson, Holling, Prictchard and Peterson (2002). The survival of phreatophytic plants under drawdown conditions depends on their ability to adjust to changes in soil moisture and groundwater depths, their capacity to tolerate periods of water stress and recruitment dynamics (Anon, 1992; Arrowsmith, 1992; Cresswell and Bridgewater, 1985). Therefore, through the study of *Banksia* woodland resilience to reduced groundwater availability we will begin to understand the balance between groundwater and *Banksias* on the Gnangara Mound.

This study will examine *Banksia* woodland communities to measure the resilience of these communities to sudden decline episodes. Changes that have occurred in vegetation composition and structure, inferred function and groundwater requirements, will be examined and contrasted with changes in communities that have not experienced sudden decline events. Specifically, this study will address the following research objectives:

1. **Identify and describe the hydrological and climatic regimes associated with sudden decline events and recovery of a *Banksia* woodland community.**

2. **Examine the floristic changes and recovery in a *Banksia* woodland community impacted by a sudden groundwater decline event.**

3. **Assess the resilience of *Banksia* woodland communities to sudden groundwater decline episodes.**

This thesis is divided into six chapters. Chapters 1 and 2 provide a background to this study and details of climatic conditions, topographical, hydrological, vegetation and environmental features of the Gnangara Mound. Chapter 3 addresses the first aim by examining the hydrological conditions preceding and following the groundwater decline event, as well as describing the climatic changes observed over the past 50 years. The second aim of the study is addressed in chapter 4, which is an examination of the floristic changes that are associated with the recovery of *Banksia* woodlands to a drawdown event. The third aim is covered by chapter 5 and essentially comprises comparisons of results observed at P50 to other sites that have not undergone a drawdown event. The other sites examined included both long-term monitored sites by Mattiske and Associates, and current status sites that were hydrologically similar to P50. The final chapter is a general discussion aimed at synthesising the results from all of the chapters, enabling conclusions to be drawn regarding the resilience of *Banksia* woodlands to drawdown.

Chapter 2

Study Site – Gnangara Mound

2.1 Location

The Gnangara Mound covers an area of about 2,140 km^2 extending from Gingin Brook and Moore River in the north to the Darling Scarp in the east, the Swan River in the South and the Indian Ocean to the west. The Gnangara Mound also recharges the deeper confined aquifers found in the area, the Leederville and Yarragadee aquifers (Waters and Rivers Commission, 1997).

The vegetation transects monitored as part of the long-term monitoring programme by the Waters and Rivers Commission are located on the northern Swan Coastal Plain, north of the city of Perth. The following transects were examined:

P50
Neaves
Yeal Swamp

The transects on the northern Swan Coastal Plain were originally established to cover a range of locations, including those near current pumping (P50), those beyond the immediate influence of pumping (Neaves) and those near proposed pumping operations (Yeal Swamp). All transects were at least 200m to 220m in length (Mattiske, 2003).

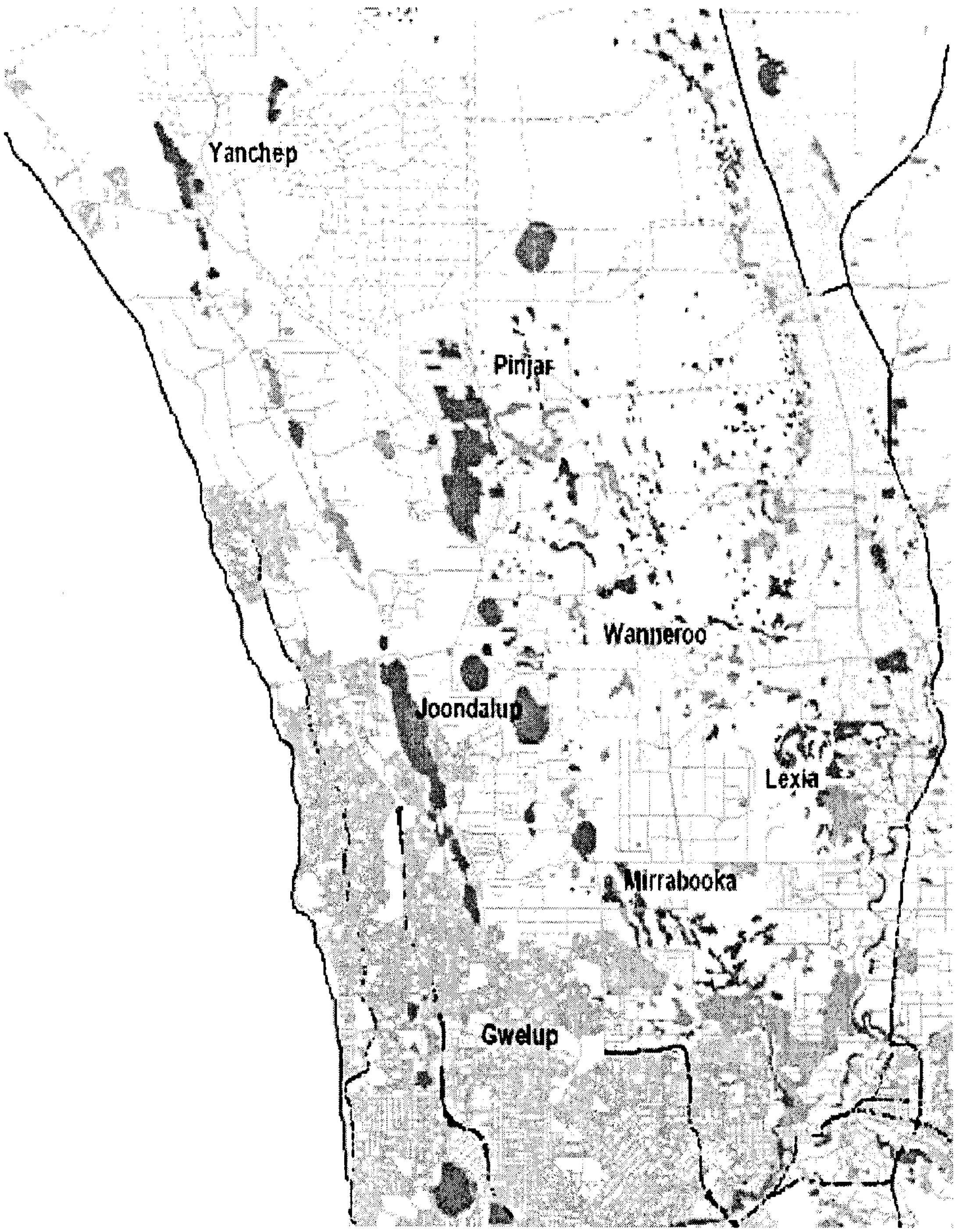


Figure 2.1 Map demonstrating the location and expanse of the Gnangara Mound (Water and Rivers Commission, 1997).

2.2 Climate

The Swan Coastal Plain experiences a typical Mediterranean climate with hot, dry summers and mild, wet winters (Mattiske, 2000; Gentilli, 1947,1951, 1972; Commonwealth Bureau of Meteorology, 1966, 1969). It is characterised by five to six dry months each year, receiving 86% of its annual rainfall between May and October (Beard, 1981). The deep leached sands that support *Banksia* woodlands have an extremely low water holding capacity, therefore, little to no water is available from the top few meters of soil during the summer months (December to February) (Dodd and Heddle, 1989).

The average maximum temperature usually occurs in the month of February and is 37° Celsius, and the coldest month being August with an average maximum temperature of 18° Celsius (Commonwealth Bureau of Meteorology, 1966, 1969).

The long-term average annual rainfall for Perth is estimated to be 780 mm per year (Commonwealth Bureau of Meteorology, 1966, 1969), however, since the commencement of monitoring at vegetation monitored sites, there has been an extended period of below average rainfall between 1970 and 2004, with only a few years exceeding average annual rainfall (Mattiske 2003). Perth's rainfall has experienced a downward trend since the 1950s (Mattiske, 2000).

In the summer months of 1990-1991 and 1993-1994, Perth experienced a series of extreme temperature days of $40^{\circ}C$ to $45^{\circ}C$, and low rainfall. These conditions led to a series of scattered deaths and pockets of deaths in plant communities from Perth to the Wheatbelt (Mattiske, 2003).

2.3 Landforms and Soils

The Swan Coastal Plain consists of a series of geomorphic entities running parallel to the coastline. It comprises of the Pinjarra Plain and three dune systems of different ages of deposits, whose soils are at different stages of leaching and soil formation.

The Pinjarra Plain is a piedmont deposit formed from the rivers that entered the Coastal Plain on its eastern side (Mattiske, 1995). It is characterised by medium-textured, fairly well drained soils and gentle slopes. Immediately to the west is the Bassendean dune system, which consists of slightly leached grey sands devoid of virtually all nutrients. This dune system is generally gently undulating, although they do reach an altitude of 60m in the north (Mattiske, 1988). Between the dunes is a series of extensive seasonal swamps with peaty soils and moist flats underlaid by organic hardpans. These minor variations in topography are also reflected by differences in the depth of the watertable, which in turn, influences the vegetation (Mattiske, 2003).

The Spearwood dune system occurs to the west of the Bassendean dune system, and is generally higher and steeper, and consists of a core of calcium-rich aeolinite with a limestone capping. The two soils associated with this area are the Karrakatta and Cottesloe soil profiles, and are separated by a series of lakes, including Lake Joondalup and Lake Nowergup on the western side of the Gnangara Mound (Mattiske, 2000).

West of the Spearwood dune system is the Quindalup dune system, consisting of a narrow belt of unconsolidated calcareous sand (Gentilli, 1947).

2.4 Water Resources

The interaction between climate, soil and geology of the Swan Coastal Plain has an important bearing on the water relations on the Gnangara Mound (Dodd and Heddle, 1989). Water use by vegetation on the Gnangara Mound is estimated to return approximately 70 to 90 percent of annual rainfall back to the atmosphere through evapotranspiration, and therefore, has a significant impact on the amount of water available to recharge the groundwater resources (Dodd and Heddle, 1989). Recharge to the Gnangara Mound Aquifer is, therefore, in the vicinity of 10 to 30 percent of the total annual rainfall on an average year (Grieve, 1956).

Studies show that the demands made on the limited water resources in the vicinity of Perth are increasing (Mattiske, 2003; Water Authority of Western Australia, 1986; Western Australia Water Resource Council, 1987). The Gnangara Mound provides a significant part of the groundwater for the Perth region and is predicted to expand to 50% of current supply over the next 15 years (Western Australian Planning Commission and Water and Rivers Commission, 1999).

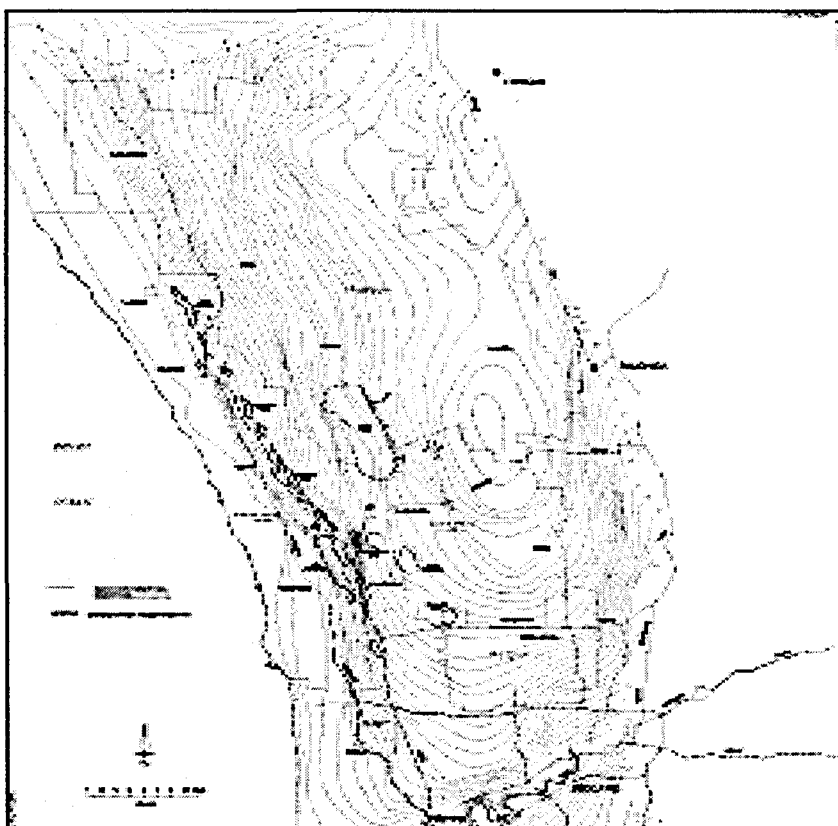


Figure 2.1 Map displaying the groundwater contours and production bores of the Gnangara Mound (Water and Rivers Commission, 1997).

2.5 Vegetation

The vegetation on the Gnangara Groundwater Mound is a complex mosaic of vegetation types, the composition of which is determined by soil conditions, position within the landscape (topography), groundwater depth and soil moisture availability. The Gnangara Mound supports many varieties of plant communities and species, with the overstorey being dominated by *Banksia, Eucalyptus* and *Melaleuca* species. Monitoring of the vegetation transects on the Gnangara Mound over a 15-year period has shown that the floristic composition is continually changing over time (Havel, 1968; Stock, van der Heyden and Lewis, 1992).

The dominant natural vegetation found across the Gnangara Mound can be defined as a *Banksia attenuata – Banksia menziesii* woodland, consisting of an open overstorey defined by these two species, with a relatively complex understorey. The majority of the species found belong to following families: Myrtaceae, Proteaceae, Fabaceae, Cyperaceae, Poaceae, Mimosaceae, Stylidiaceae and Orchidaceae.

Chapter 3

Hydrological and climatic regimes associated with sudden decline events and recovery of a *Banksia* woodland community.

3.1 Introduction

The assessment of the condition of any vegetative community, and in this case, the resilience of *Banksia* woodlands to groundwater drawdown, is dependent upon a complete understanding of the factors influencing that particular plant community (Sharma, 1989). The main determinates influencing the location of different plant communities on the Gnangara Mound are the underlying site conditions and depth to groundwater, both of which fluctuate on a seasonal basis. For example, *Banksia ilicifolia* can be found in the middle to lower slopes and depressions where depth to groundwater is relatively low and other species such as *Banksia attenuata* and *Banksia menziesii* are found across a topographical gradient as they can tolerate a greater range in conditions (Allen, 1981).

The Bassendean dune system forms a part of the northern Swan Coastal Plain under which lies a large shallow unconfined aquifer, the Gnangara Groundwater Mound. Groundwater and soil moisture levels have been gradually decreasing in most areas of the Gnangara Mound since the 1970s as a combined result of a number of years of below average rainfall, increased groundwater abstraction and increased pressures from the users of the Gnangara Mound groundwater resource (Davison, 1995). The Gnangara Mound is the largest and most important shallow underground water resource in the Perth region and it supplies substantial amounts of water to meet Perth's current water demand, therefore, being a vital resource to the Perth metropolitan region (Heddle, 1986).

Water use by *Banksia* woodlands on the Gnangara Mound is estimated to return approximately 70 to 90 percent of annual rainfall back to the atmosphere through evapotranspiration, and therefore, has a significant impact on the amount of water available to recharge the groundwater resources (Dodd and Heddle, 1989). The various seasonal patterns of transpiration and water stress that have been measured in a range of

Banksia woodland trees and shrubs closely reflect plant rooting depths, and consequently, the nature and longevity of the groundwater supply (Grieve, 1956).

The seasonal pattern of transpiration and water stress, referred to in the above paragraph, is related to the seasonal and annual water budgets required by plants. Dodd and Bell (1993), in a paper examining the water use by *Banksia* woodlands, described a number of trends associated with *Banksia* woodland communities on the Swan Coastal Plain, which are related to annual and seasonal water budgets. In winter and early spring it can be assumed that virtually the entire demand for water by vegetation is met by soil storage, with approximately a 40 percent to 60 percent split in water use between understorey and canopy species respectively (Dodd and Bell, 1993).

Throughout the summer months Dodd and Bell (1993) conclude that a *Banksia* woodland community's water use greatly exceeds the total rainfall and the change in soil water storage in any one community; i.e. in a 12-month water cycle the components of the water budget are not at equilibrium with summer usage exceeding supply and decreasing winter rainfall not allowing full recharge of the soil profile to permit restoration of the watertable to its original position (Dodd and Bell, 1993).

The growing trend across the Gnangara Mound defining the relationship between water stress induced by declining watertable levels is due to a combination of changing climatic and environmental conditions, and an increase in the pressures by the main users of this groundwater resource. Low winter rainfall and increasingly longer dryer summers has resulted in a declining watertable level observed across the Gnangara Mound (Grieve, 1956). It is at P50 where external abstraction interferes with the balance between climate, groundwater and soil moisture, that a collapse of a natural vegetation community was experienced, due to increased drawdown pressures on the watertable during a particular vulnerable point in the vegetation's history.

The impact and consequence of groundwater and climatic changes on phreatophytic vegetation ranges from gradual changes in community composition over decades, to sudden and extensive vegetation deaths (Groom, Froend and Mattiske, 2000a). Gradual changes in *Banksia* woodlands due to reduced soil water availability occur over a relatively long period of time, and a gradual change in species composition and community structure has been observed (Froend et al 2000a). Overstorey species that cannot tolerate long periods of reduced soil water availability have been recorded to be slowly dying out and being replaced by more drought-tolerant species.

A more acute and noticeable response to groundwater and climatic change are events that cause sudden and extensive vegetation deaths. This form of response had occurred when rapid groundwater drawdown was combined with low rainfall recharge rates (McArther, 1986). An example of this response was the summer of 1990/1991 event, where up to 80% of all *Banksia* trees and 60-70% of the understorey died within the vicinity of P50, a production bore in the Pinjar borefield. Although the vegetation is recovering, little is known about the possible changes that have occurred to vegetation characteristics, i.e. whether the recovered vegetation characteristics are significantly different in composition, function and groundwater requirements.

The aim of this chapter is to characterise the hydrological and climatic changes that have led to the sudden decline episode observed in the *Banksia* woodland community at P50, and the hydrological conditions associated with the recovery of this community since the summer of 1990/1991.

3.2 Methods

3.2.1 Site Selection.

The site selected was impacted by sudden groundwater decline events and had suitable historic vegetation and hydrographic datasets. This site was a production bore known as P50, which is located in the Pinjar borefield. Groundwater levels and vegetation characteristics have been monitored (pre- and post impact) for 18 and 15 years respectively and were available from the Department of Environment for this project. This site is an example of one of the most significant impacts of abstraction operations on native *Banksia* vegetation. In the summer of 1990/1991 the area surrounding this production bore suffered severe vegetation loss, where up to 80% of all *Banksia* trees died (Mattiske and Associates, 2000). This tree mortality was attributed to a rapid drawdown of the watertable as a result of increased summer abstraction (Kite and Webster, 1989) and decreased winter recharge at the site.

Neaves and Yeal Swamp were the two long-term monitored sites that contained sufficient hydrological and vegetation data suitable for this study. The other 12 of Mattiske and Associates long-term monitored sites were all unsuitable, because they were not in the same vegetation complex or their hydrological pattern was considerably different. Neaves and Yeal Swamp were both located in the same vegetation complex and had not undergone a drawdown event.

3.2.2 Source of Records.

The hydrographical and climatic data for this study were available from a number of sources. Hydrographic data was sourced from the Waters and Rivers Commission, where regular monitoring of the bores are collected and archived. The hydrological data was obtained for a number of important production and monitoring bores throughout the Gnangara Mound.

The climatic data was obtained from the Bureau of Meteorology and analysed to produce the required information. Data obtained included daily and monthly temperature data for the Perth and Wanneroo regions, along with daily and monthly rainfall data for these two areas. Drill data was obtained from the Bureau of

Meteorology's SILO website and consists of modelled data for a particular set of entered coordinates. This data was modelled from surrounding meteorological stations to give a dataset that was representative of the site requested. A combination of temperature, rainfall, rain days, evaporation, wind conditions, cloud cover, were used to predict this data. This data was only requested for the P50 production bore, because, due to the nature of the modelled data the study sites were closer together than the meteorological stations themselves.

3.2.3 Analysis of Data.

Hydrological data at the P50 production bore was assessed along with that of the P50-vegetation (P-veg) observation bores one to three. The annual maximum and minimum for each year at the above-mentioned four bores was analysed and graphed, along with the annual rate of groundwater decrease (metres/month). This data was then enhanced and examined closely surrounding the drawdown event to obtain an understanding of the characteristics leading up to such an event. Similar hydrographic data was also examined for the two long-term monitored sites Neaves and Yeal Swamp to establish a link between the P50 production bore and sites that have not been affected by a drawdown event.

The hydrograph for the P50 production bore supplied by the Waters and Rivers Commission is missing data after the drawdown event. This dataset has been completed using extrapolated data devised by combining the trends in climatic data, rainfall data, abstraction rates from the P50 production bore and groundwater fluctuation in surrounding monitoring bores.

Climatic data was examined for Perth from the Perth Airport monitoring station, along with data from the Wanneroo region. Monthly maximum temperatures, maximum summer temperatures (December to April), annual rainfall, winter (May to August) and summer (December to April) rainfall, monthly evaporation and maximum summer evaporation were assessed for the Perth based datasets. The climatic data obtained for the Wanneroo region concentrated on rainfall data only and consisted of annual rainfall patterns, summer rainfall (December to April) and winter rainfall (May to August).

The third set of climatic data was modelled data obtained from SILO, a modelling program at the Bureau of Meteorology, and is classified as Drill Data for the P50 bore, location 31^0 36' S and 115^0 48' S. This data describes the monthly maximum temperature, maximum summer rainfall (December to April), annual rainfall and monthly effective rainfall.

3.3 Results

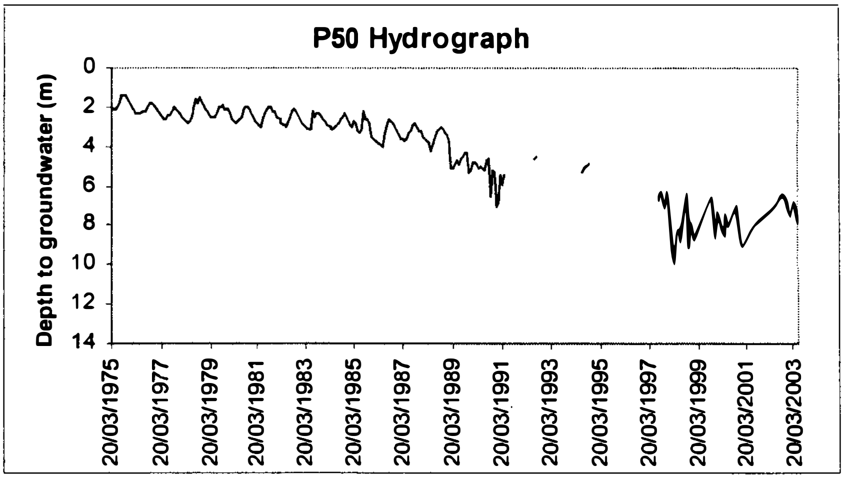
3.3.1 Hydrological pattern at P50, Neaves and Yeal Swamp prior to drawdown event.

It was the use of the production bore P50 combined with changes in environmental conditions and pressures on the groundwater level that caused the sudden groundwater decline episode, which had a devastating effect on the surrounding vegetation (Groom, Froend, Mattiske and Gurner, 2000b). The transect at this location starts at the P50 production bore and runs parallel with the P50-vegetation monitoring bores. Both the hydrographic data from the three P-veg monitoring bores and the P50 production bore were examined to get an idea of the hydrographical trends that had occurred. The hydrological regime at Neaves and Yeal Swamp was also examined and compared the trends observed at P50 to trends at non-impacted sites.

Over the monitored history at P50 there is a definite trend that develops, demonstrating a lowering of the watertable from around 2.2m in 1975 to a depth of 7.9m in 2003. However, the factor that makes the hydrograph for P50 unique is the sudden groundwater decline episode that occurred in 1988 through to 1990, from 3.9m to 7.1m respectively (Figure 3.1).

By examining closely the changes that occurred prior to the collapse at P50, it can be notated that the annual fluctuations leading up to 1989 are relatively normal seasonal variations (Figure 3.1). In 1989 the P50 production bore was commissioned (Figure 3.4) and it was from this period that an observable decline in the watertable was detectable. Between 1989 and 1990 the water table dropped significantly and then fluctuated very rapidly with short sharp peaks between minimum and maximum groundwater levels (Figure 3.1). The bore was then shut down during the winter of 1989 and the watertable level started to recover. The watertable then dropped rather significantly when the bore was turned on during the summer of 1989-1990, which pushed the *Banksia* woodland to maximum stress levels and resulted in the *Banksia* woodland deaths observed in 1991.

a)



b)

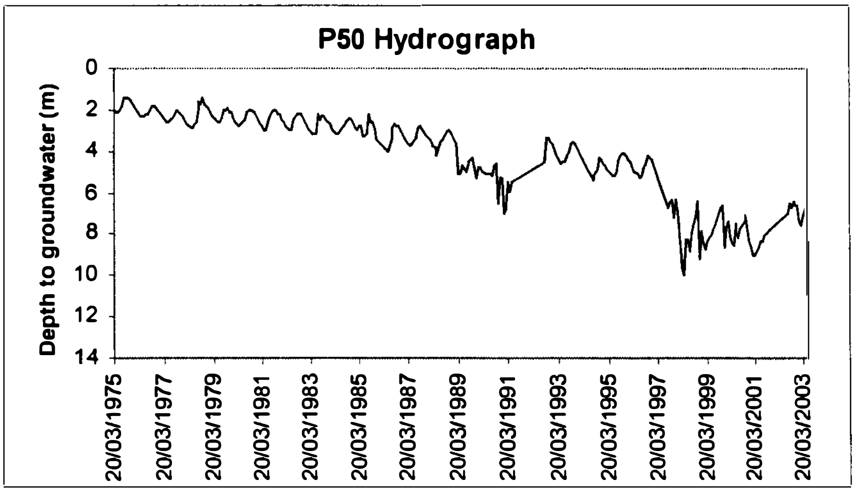


Figure 3.1 **a)** Hydrograph of the production bore known as P50. Hydrograph is incomplete due to an incomplete data set.

b) Hydrograph of P50. This hydrograph contains data that has been extrapolated using environmental conditions. The hydrograph for the P50 production bore supplied by the Waters and Rivers Commission is missing data post the drawdown event. This dataset has been completed using extrapolated data devised by combining the trends in climatic data, rainfall data, abstraction rates from the P50 production bore and groundwater fluctuation in surrounding monitoring bores.

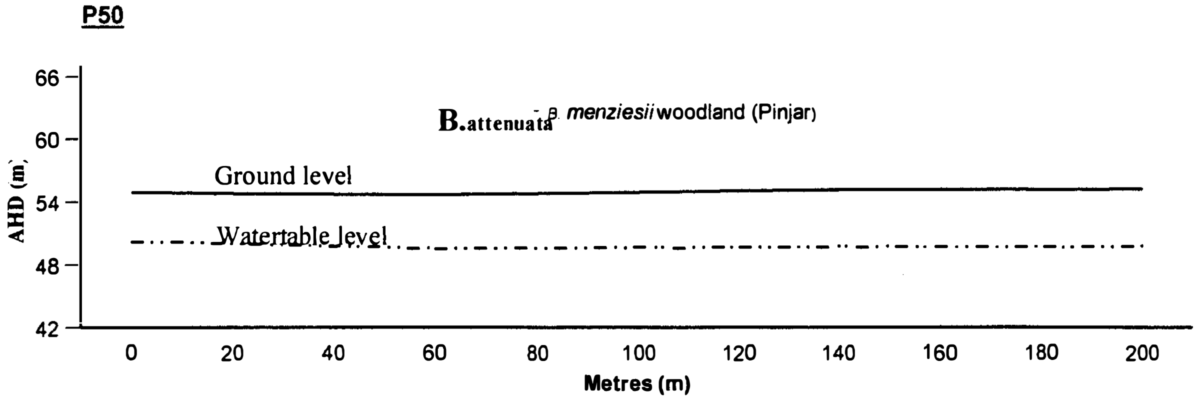
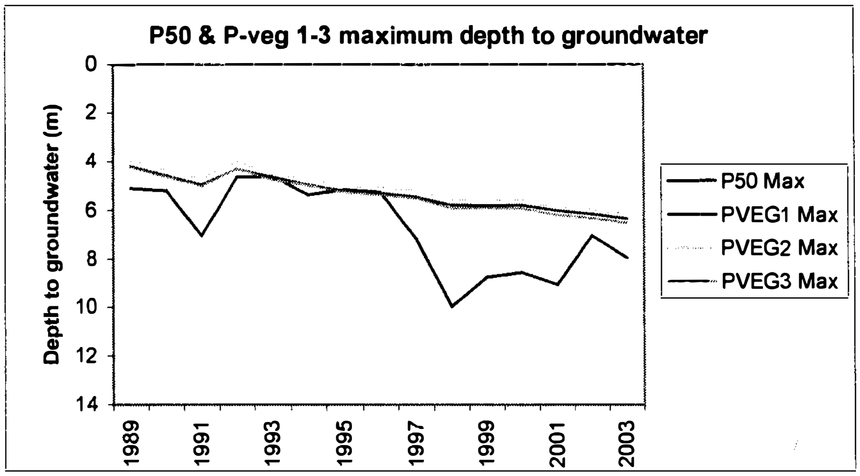


Figure 3.2 Transect at P50 showing length, ADH (m), and positioning of vegetation communities (Mattiske and Associates, 1995).

a)



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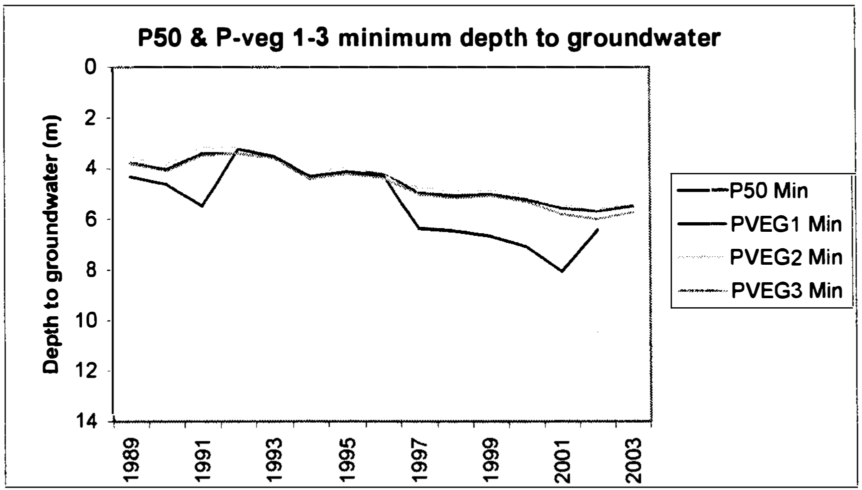


Figure 3.3 **a)** P50 and P-veg bores 1-3 annual maximum depth to groundwater data, in metres 1989-2003.
b) P50 and P-veg bores 1-3 annual minimum depth to groundwater data, in metres 1989-2003.

The bores surrounding the P50 production bore consist of the three P50-vegetation monitoring bores. These bores are located at 50 metre intervals running parallel to the vegetation transect at P50. There is a close relationship between the trends and fluctuations observed in all three of the P-veg bores, demonstrating a distinct gradual lowering of the watertable over time (Figure 3.3). Although this trend was also observed at the P50 production bore, there are no sudden or rapid fluctuations in the P50-vegetation bores data series, suggesting that they were not affected by the sudden groundwater decline episode observed at the production bore.

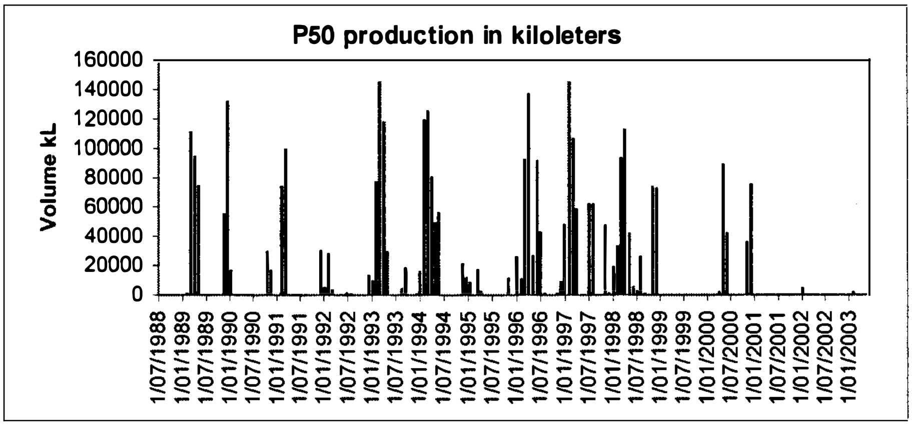
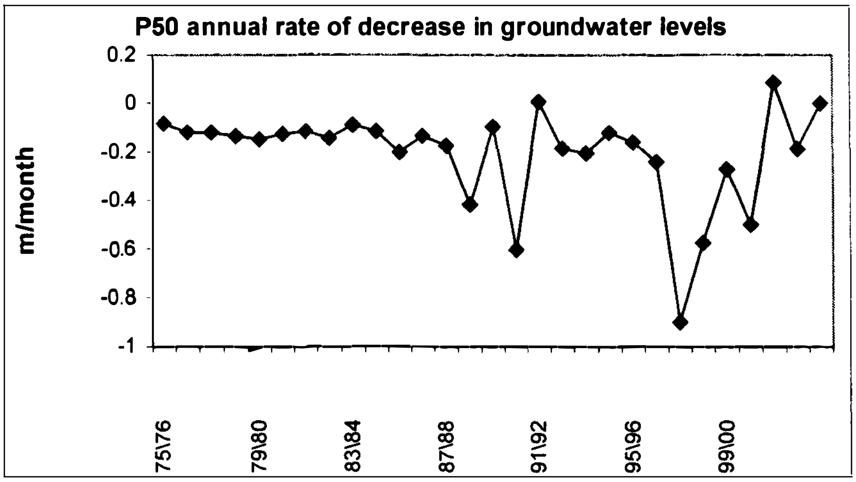


Figure 3.4 P50 production bore abstraction dates and volumes in kL (kilolitres), from the commission of the bore in 1989 to 2003.

The annual rate of decrease observed at the P50 production bore (Figure 3.5) remained relatively stable until 1988. The trend observed here supports the gradual decline in the groundwater level over time shown in Figure 3.1. In 1988 the rate of decrease increased rapidly and did not fully recover until after the vegetation deaths at the P50 production bore were observed. This increased rate of decrease coincides with the commissioning of the P50 production bore (Figure 3.4).

The rate of decrease at the P50-vegetation monitoring bores (Figures 3.6, 3.7 and 3.8) remained stable around the time of the drawdown event. There were no rapid fluctuations or sudden increase in this rate to indicate that these bores were affected by sudden groundwater decline. The rates of decrease observed at these bores were similar to that observed at the P50 production bore prior to the drawdown event occurring.

a)



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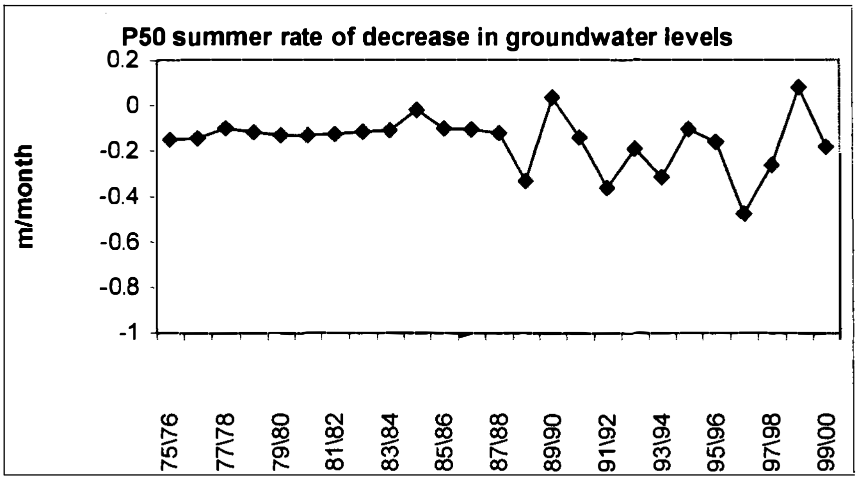


Figure 3.5 **a)** Annual rate of groundwater level decrease at P50 between 1975 - 2002.
b) Summer (December to April) rate of groundwater level decrease at P50 between 1975 - 2002.

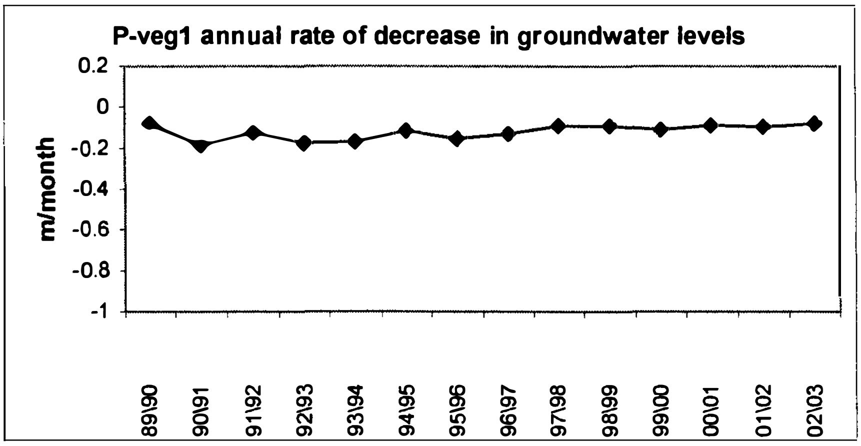


Figure 3.6 Annual rate of groundwater level decrease at P-veg 1 between 1989 - 2003.

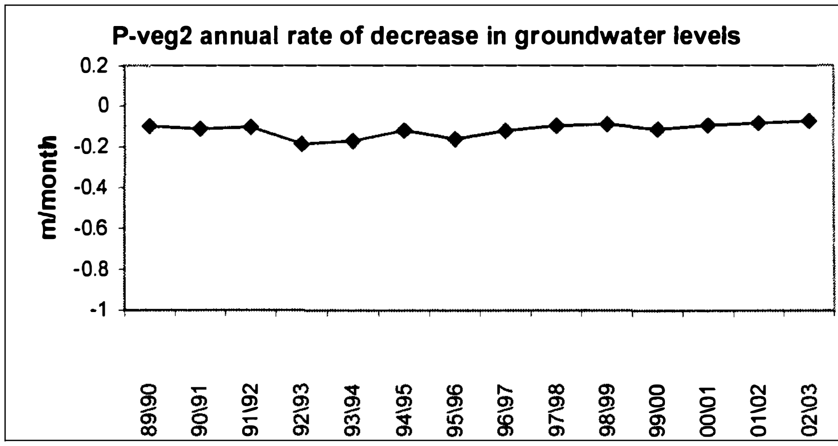


Figure 3.7 Annual rate of groundwater level decrease at P-veg 2 between 1989 - 2003.

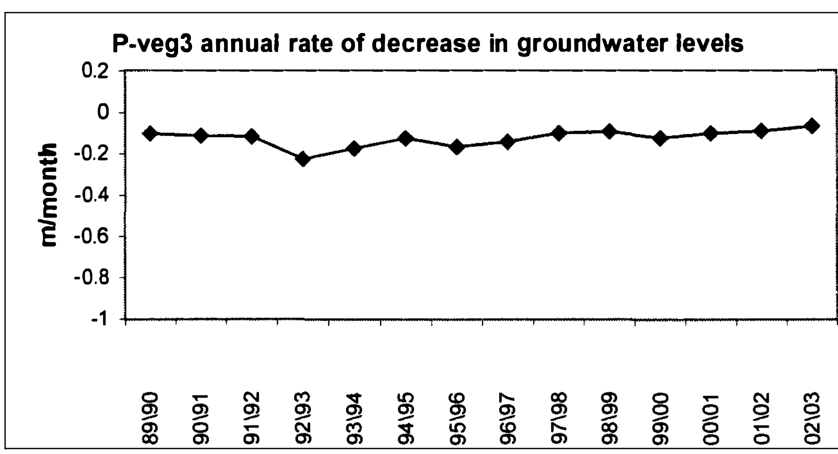


Figure 3.8 Annual rate of groundwater level decrease at P-veg 3 between 1989 - 2003.

The hydrographs for Neaves and Yeal Swamp (Figures 3.9 and 3.10) displayed a number of trends that were similar to the P50 production bore. At both Neaves and Yeal Swamp a lowering of the watertable had been observed during the entire length of the monitoring period. Neaves displayed a steady decline in the watertable level between 1975 and 1989 with normal seasonal fluctuations observed. The annual rate of decrease observed at Neaves (Figure 3.12) also demonstrates this trend with a constant rate of decrease around 10cm per month. Although the hydrograph for Yeal Swamp (Figure 3.10) also displayed this trend, the depth to groundwater in 1977 was deeper than that observed at the P50 production bore. Between 1977 and 1985 the watertable level at Yeal Swamp remained relatively stable. In 1985 to 1989 an observable decrease in the depth to groundwater was seen, which demonstrates recharge to this system at this time. The trend in the annual rate of decrease is identical to that observed at Neaves and no indication of a drawdown event was observed.

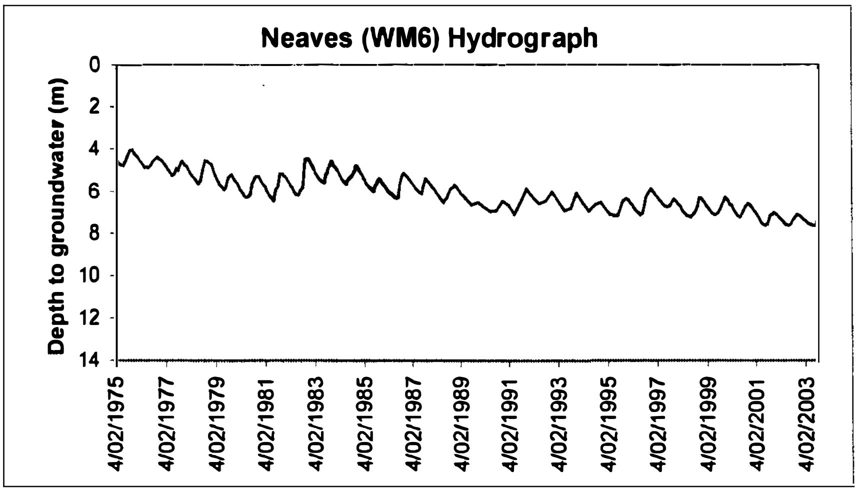


Figure 3.9 Hydrograph for monitoring bore WM6 located near the Neaves vegetation transect. Data is measured in depth to groundwater (m) and is for the period 1975 to 2003.

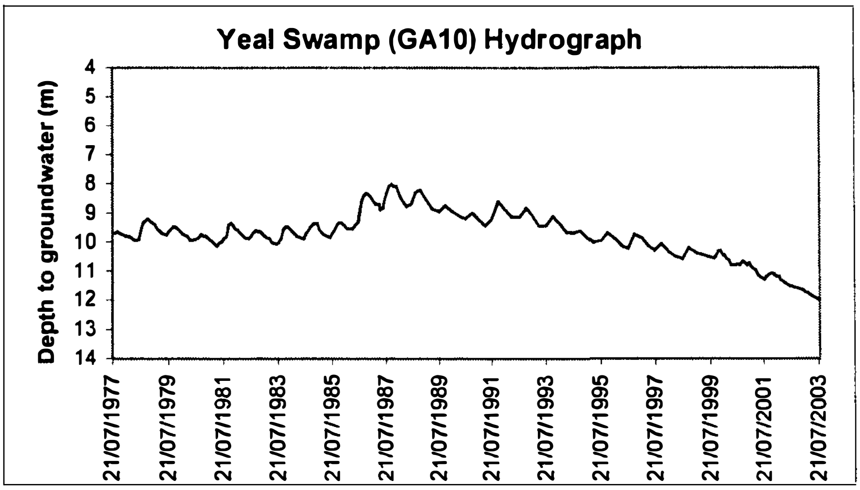
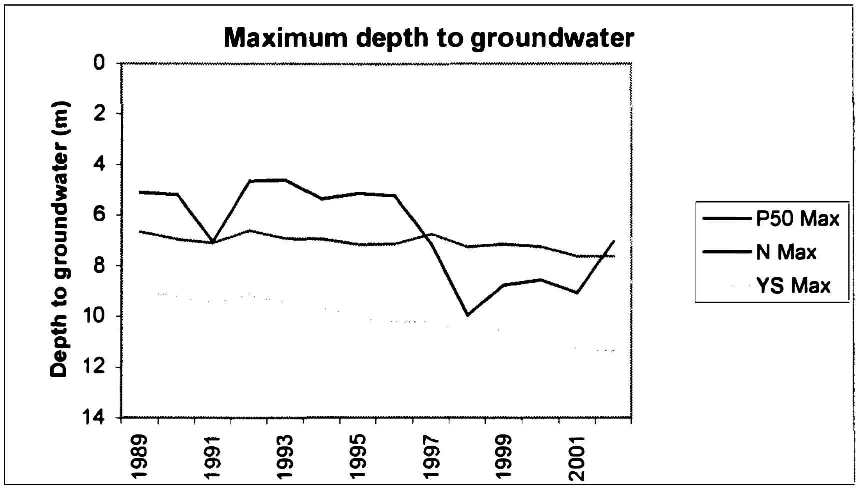


Figure 3.10 Hydrograph for monitoring bore GA10 located near Yeal Swamp vegetation transect. Data is measured in depth to groundwater (m) and is for the period 1977 to 2003.

The maximum and minimum depths to groundwater for P50, Neaves and Yeal Swamp have been compared to highlight the drawdown event at P50 (Figure 3.11). The graph in Figure 3.11a clearly demonstrates that the sudden decline event at P50 in 1989 – 1990 that is not evident in the other two data sets. Figure 3.11b shows the difference in the minimum depth to groundwater at P50, Neaves and Yeal Swamp over time.

a)



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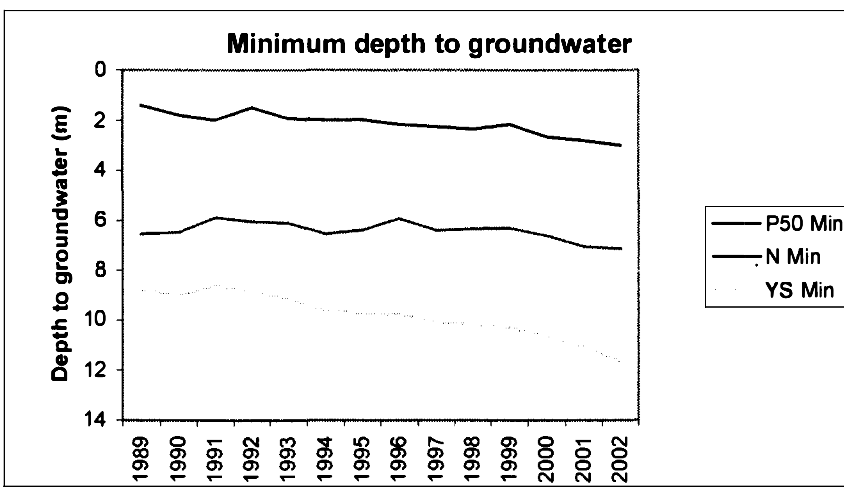
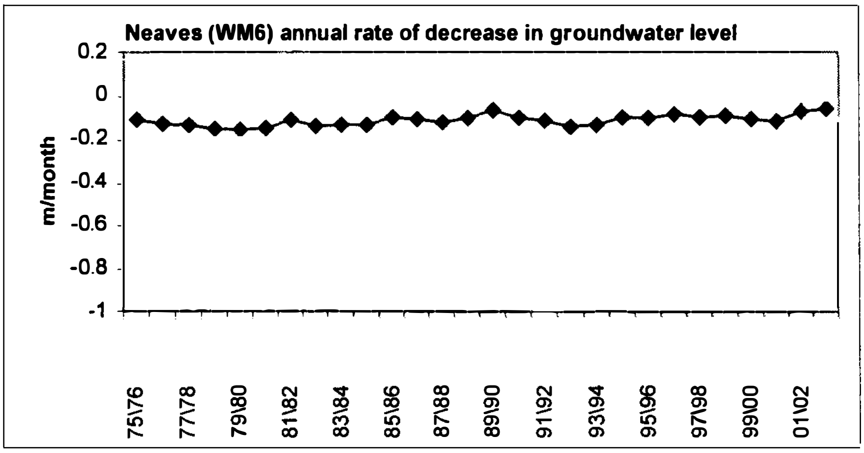


Figure 3.11 **a)** Hydrograph displaying maximum depths to groundwater for P50, Neaves and Yeal Swamp, from 1989 to 2002.
b) Hydrograph displaying minimum depths to groundwater for P50, Neaves and Yeal Swamp, from 1989 to 2002.

The following two graphs in Figure 3.12 demonstrate the annual rate of decrease observed at Neaves and Yeal Swamp. It can be observed that P50's rate of decrease fluctuated quite rapidly surrounding the sudden decline event and at other points when the production bore was turned on (Figure 3.5). Neaves and Yeal Swamp are different from P50 in that the rate of decrease in groundwater level is relatively uniform and both average about 10mm decrease per month. This follows the general trend on the Gnangara Mound of a decreasing groundwater level over time.

a)



b)

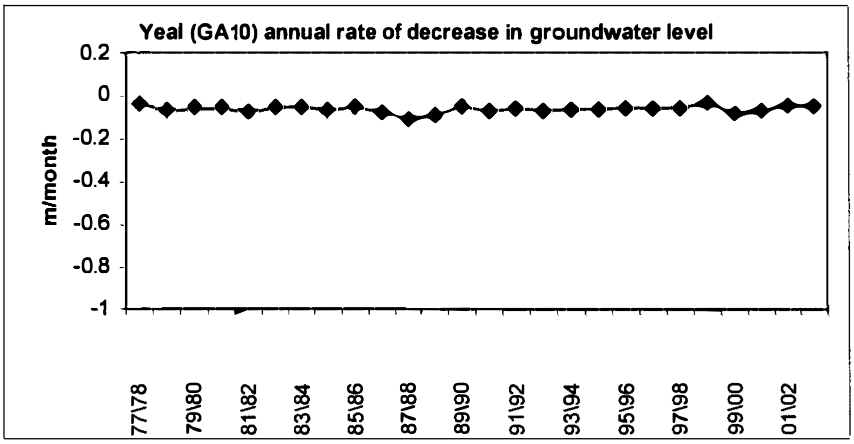


Figure 3.12 **a)** Annual rate of groundwater level decrease at Neaves between 1975 - 2003.
b) Annual rate of groundwater level decrease at Yeal Swamp between 1978 - 2003.

3.3.2 Hydrological pattern at P50, Neaves and Yeal Swamp following the drawdown event.

In the summer of 1990/1991 the Waters and River Commission observed the changes in the *Banksia* woodland surrounding the P50 production bore and decreased abstraction immediately (Figure 3.4). This allowed the recovery of the watertable to a level similar to those observed prior to the drawdown event (Figure 3.1). Between 1992 and 1997 the watertable at the P50 production bore continued to decrease, but the characteristics in the seasonal variations observed were identical to those pre-drawdown. In 1997 another drawdown event had been observed due to the recommissioning of the P50 production bore; however, no vegetation loss is linked to this drawdown event.

The graphs displaying the rate of decrease at the P50 production bore also demonstrated this trend (Figure 3.5 a and b). Between 1992 and 1997 the annual rate of groundwater decrease returns to pre-drawdown rates, and in 1997 the rate of decrease dramatically increased, coinciding with abstraction from the P50 production bore (Figure 3.5).

The trend observed at the P-veg bores remained constant, with a steady rate of decrease observed. No major changes in the observed hydrological decline were experienced at these sites (Figures 3.3, 3.6, 3.7 and 3.8).

Post 1990, the trends at Neaves and Yeal Swamp changed very little. The groundwater level decline observed continued at a steady rate (Figure 3.9 and 3.10). Neaves annual rate of decrease continued to be about 10cm per month and no observable fluctuations occurred (Figure 3.12). After the increase in the groundwater level at Yeal Swamp between 1985 and 1989, the groundwater levels continued to decrease at a steady rate. The annual rate of decrease at Yeal Swamp also decreased at a steady rate and remained at about 10cm per month (Figure 3.12).

3.3.3 Climatic patterns for Perth, Wanneroo and P50.

Perth climatic conditions fluctuate greatly over time and season variability had been observed. The following section aims to examine the climatic changes for Perth, Wanneroo and P50 surrounding the sudden decline episode. The pattern for Perth's maximum temperature demonstrates an increasing trend from 1950 to 2003. This has been observed in the 5 year moving average, with an increase in average temperature from 23 degrees in 1950 to 27 degrees Celsius in 2003 (Figure 3.13).

The increase in average temperature between 1950 and 2003 was highlighted in the maximum summer temperature for Perth (December to April) (Figure 3.14). There is an observable increase in the 5 year moving average from 30 degrees to 34 degrees Celsius over the monitored history. Surrounding the drawdown event there are a couple of peaks in maximum summer temperature in 1955 and 1994 compared to the other years surrounding this event.

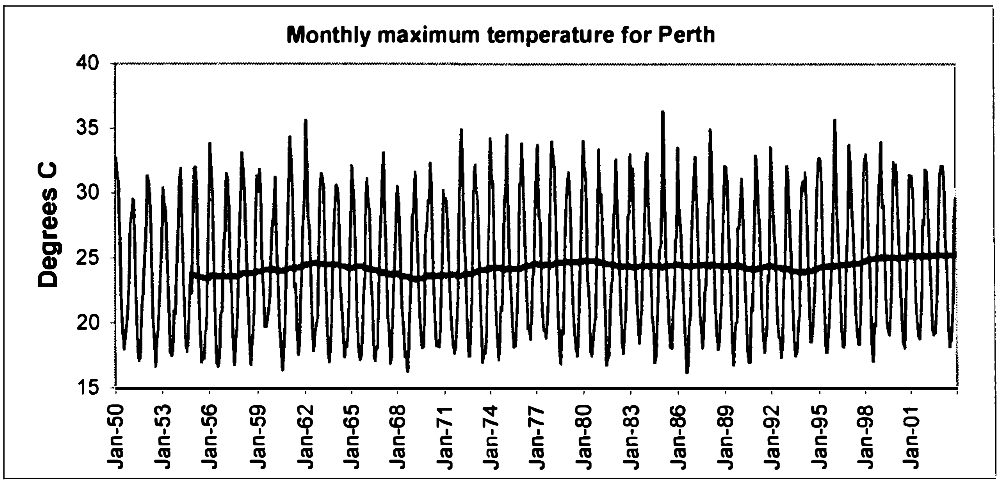


Figure 3.13 Monthly maximum temperature for Perth from 1950-2003. Graph shows maximum temperature and the 5 yearly moving average. Temperature taken from Perth Airport, Belmont W.A., Station Number 9021 (Latitude 31°55'35"S, Longitude 115°58'35"E, Elevation: 15.4m)

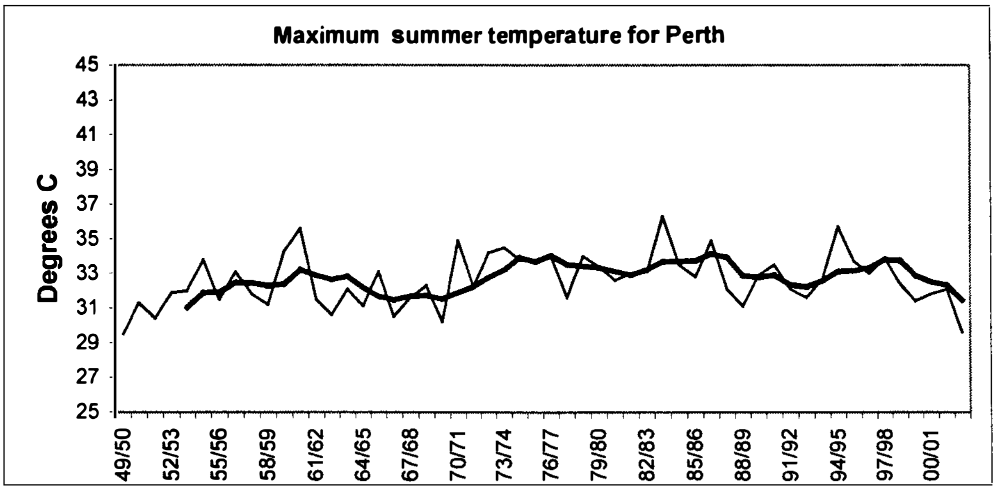


Figure 3.14 Summer (December to April) maximum temperature for Perth from 1950-2003. Graph shows maximum temperature for this period and the 5 yearly moving average. Temperature taken from Perth Airport, Belmont W.A., Station Number 9021 (Latitude 31°55'35"S, Longitude 115°58'35"E, Elevation: 15.4m)

Leading up to the drawdown event at the P50 production bore there was a decrease in the average annual rainfall between 1968 and 1986 (Figure 3.15). This trend was also observed in the winter (May to August) rainfall patterns, with a decreasing amount of rainfall received between 1950 and 2003. Summer rainfall (December to April), prior to the drawdown event fluctuated greatly between 1950 and 1975, where at this point, a gradual increase was observed until 1988. In 1988 the summer rainfall peaked and 230mm of rainfall was received. Between 1988 and 1992 the amount of summer rainfall decreased dramatically, decreasing recharge for the years surrounding the drawdown event.

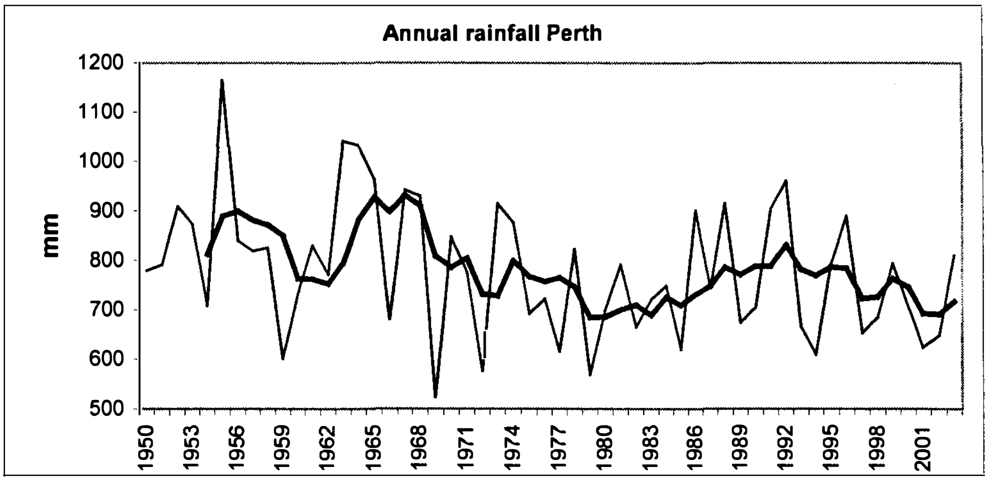
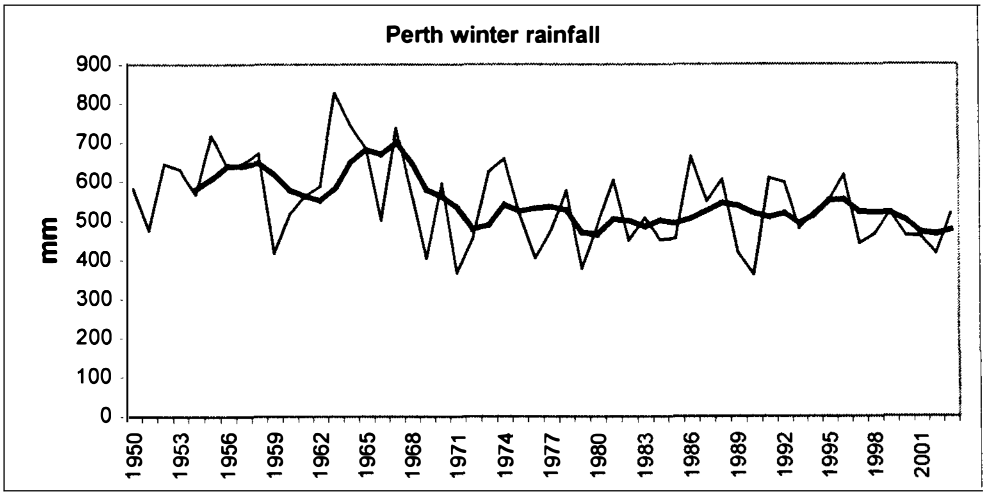


Figure 3.15 Annual rainfall for Perth from 1950-2003. Graph shows annual rainfall and 5 year moving average. Rainfall measurements taken from Perth Airport, Belmont W.A., Station Number 9021 (Latitude 31°55'35"S, Longitude 115°58'35"E, Elevation: 15.4m)

Following the draw down event at the P50 production bore the average maximum summer temperature continued to rise (Figure 3.14). The average annual rainfall patterns following this event increased slightly with a number of wetter years observed (Figure 3.15). Perth's winter rainfall patterns continued, with decreased average winter rainfall over time (Figure 3.16). After the dry summers experienced between 1988 to 1992, a wet summer was observed where 240mm of rainfall was received. Following this peak in summer rainfall a number of very dry summers were observed, with an increase in summer rainfall again in 1999 (Figure 3.16).

Evaporation data had been modelled from other climatic data sets. The Pan evaporation for Perth showed that little change had occurred over time at this level, with a slight increase in evaporation rates observed between 1992 and 2000 (Figure 3.17). The maximum summer evaporation level showed that following the event, the maximum summer evaporation increased rather sharply and remained high between 1992 and 2000.

a)



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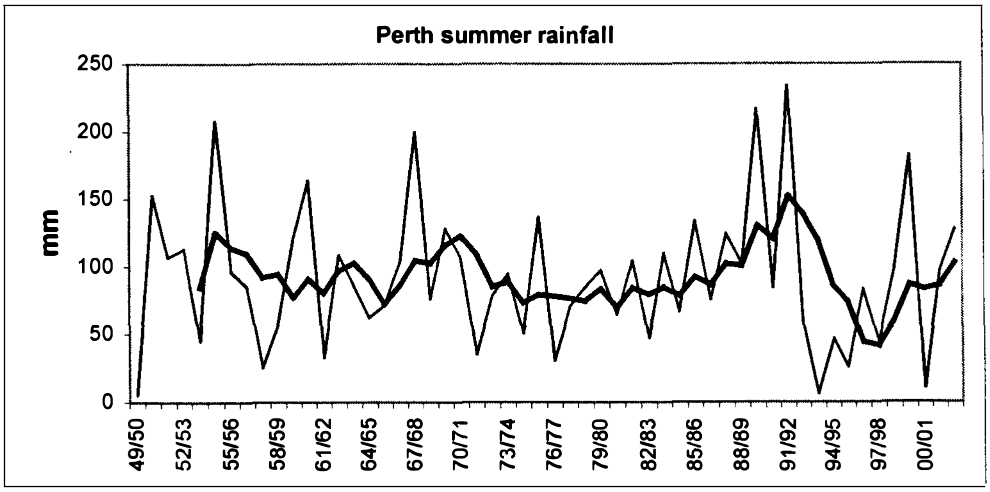
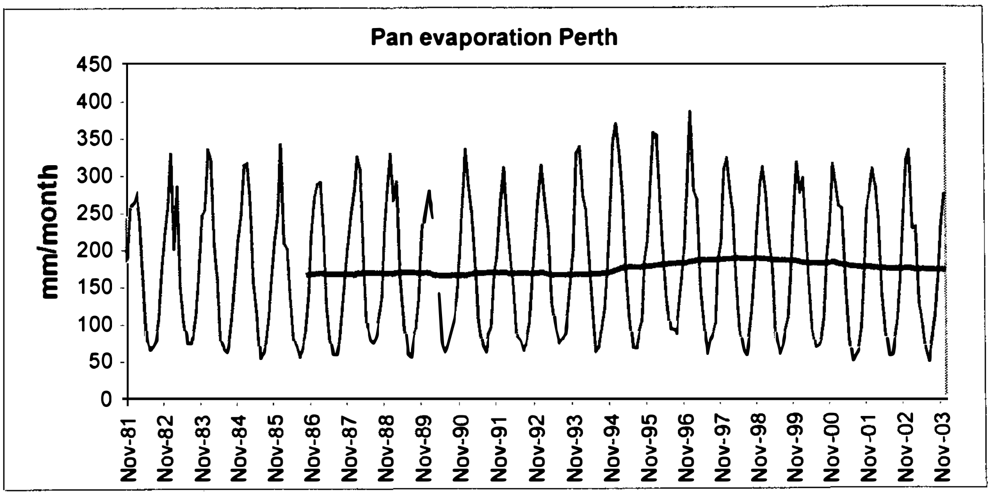


Figure 3.16 **a)** Winter (May to August) rainfall for Perth from 1950-2003 (May to August). Graph shows winter rainfall and 5 year moving average. Rainfall measurements taken from Perth Airport, Belmont W.A., Station Number 9021 (Latitude 31°55'35"S, Longitude 115°58'35"E, Elevation: 15.4m)

b) Summer (December to April) rainfall for Perth from 1950-2003 December to April. Graph shows summer rainfall and 5 year moving average. Rainfall measurements taken from Perth Airport, Belmont W.A., Station Number 9021 (Latitude 31°55'35"S, Longitude 115°58'35"E, Elevation: 15.4m)

a)



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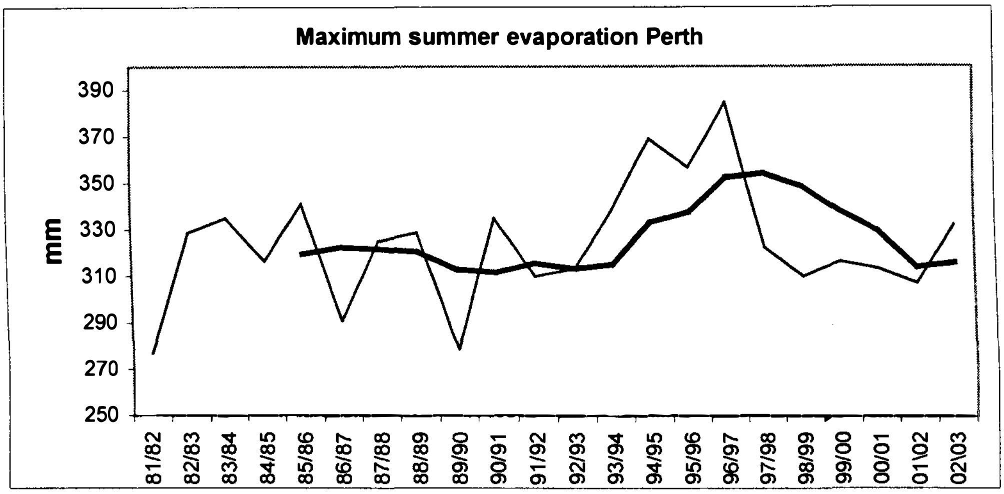
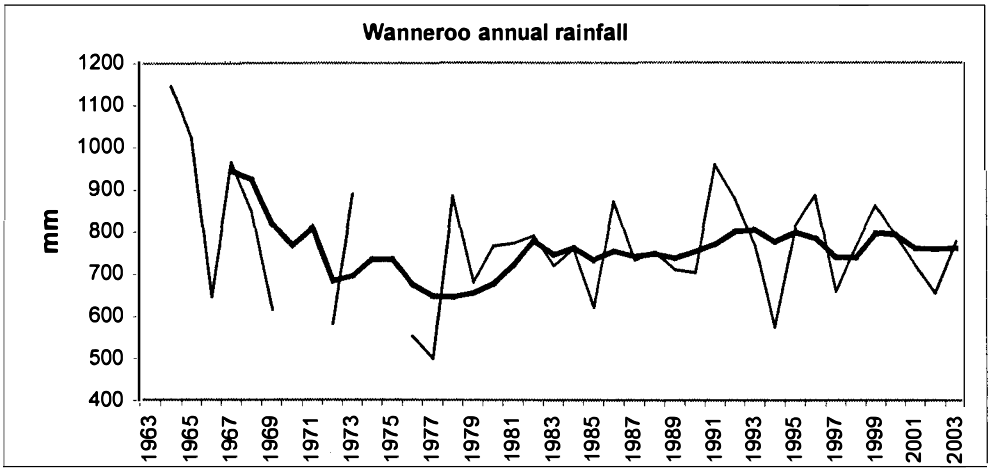


Figure 3.17 **a)** Pan Evaporation for Perth from 1981-2003. Graph shows monthly Pan evaporation in mm and 5 year moving average. Pan evaporation measurements taken from Perth Airport, Belmont W.A., Station Number 9021 (Latitude 31^{0}55'35"S, Longitude 115^{0}58'35"E, Elevation: 15.4m). Evaporation data is modelled data.
b) Max summer (December to April) Pan evaporation for Perth from 1981-2003. Graph shows max Pan evaporation (mm) for summer and 5 year moving average. Pan evaporation measurements taken from Perth Airport, Belmont W.A., Station Number 9021 (Latitude 31^{0}55'35"S, Longitude 115^{0}58'35"E, Elevation: 15.4m). Evaporation data is modelled data.

The rainfall patterns observed at Wanneroo showed similar trends to those observed at Perth. Although the rainfall for Wanneroo remains relatively steady from 1975 to 2003, a distinct drop in rainfall between 1987 and 1992 was observed (Figure 3.18a). This trend was also observed in the winter rainfall graphs, demonstrating a decrease in rainfall during this period (Figure 3.18b). However, the summer rainfall patterns recorded at Wanneroo indicated two peaks either side of the drawdown event, one in 1989 and the other in 1993. In between these peaks the rainfall received is well below average and coincides with the drawdown event (Figure 3.18c).

a)



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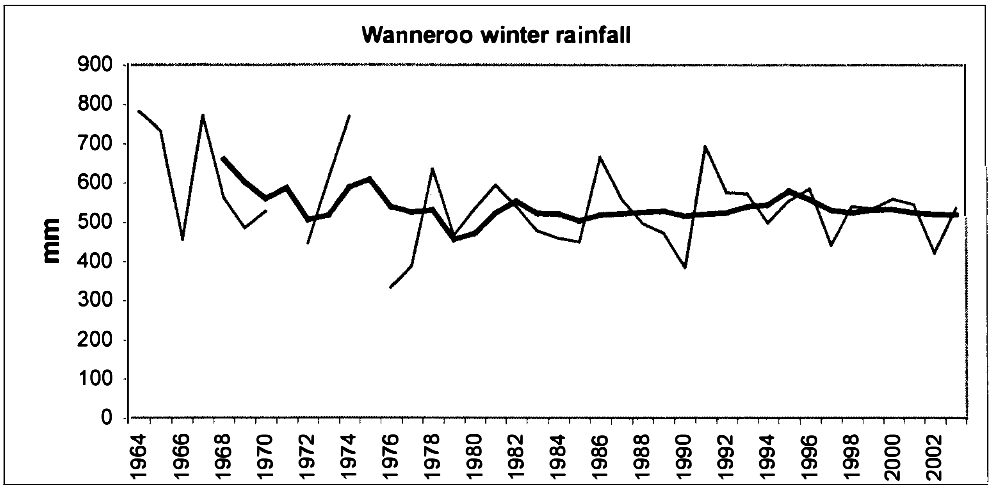


c)

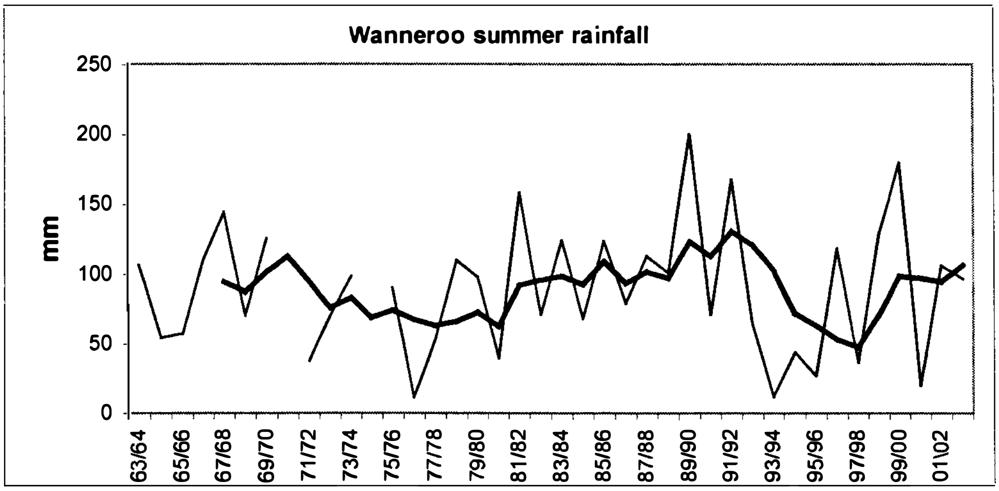
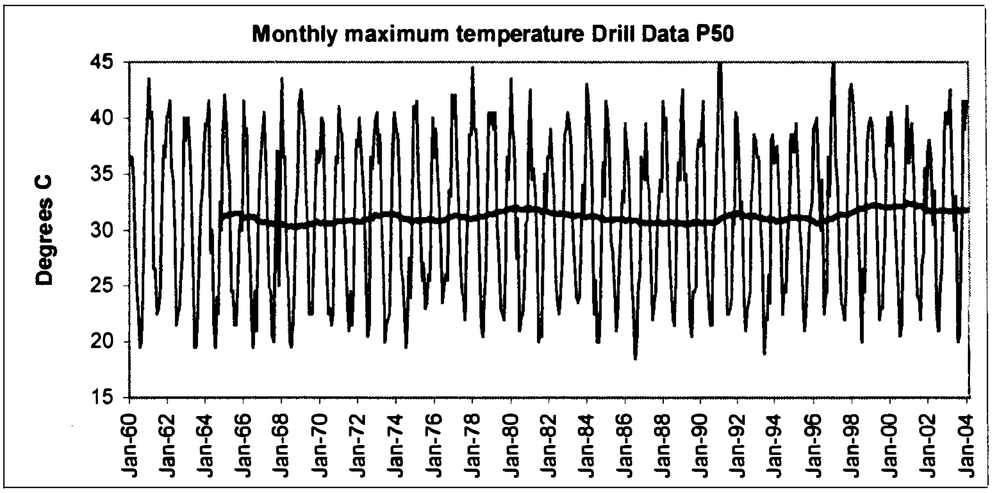


Figure 3.18 **a)** Annual rainfall for Wanneroo from 1963-2003. Graph shows annual rainfall and 5 year moving average.
b) Winter rainfall (May to August) for Wanneroo from 1964 - 2003. Graph shows winter rainfall (May-Aug) and 5 year moving average.
c) Summer rainfall (December to April) for Wanneroo from 1964 - 2003. Graph shows summer rainfall (Dec-Apr) and 5 year moving average.

Drill data was modelled by a program known as SILO at the Bureau of Meteorology (Figures 3.19 and 3.20). The data is modelled from the P50 production bore with the following co-ordinates, 31^0 36' S and 115^0 48' E. Due to the nature of modelled data, the Drill Data for the P50 production bore was observed to be identical to the trends found at Wanneroo and Perth. Decreased rainfall patterns and high summer temperatures in 1990/1991 were all observed at the P50 production bore. Monthly effective rainfall demonstrated a consistent trend and no abnormalities were observed.

a)



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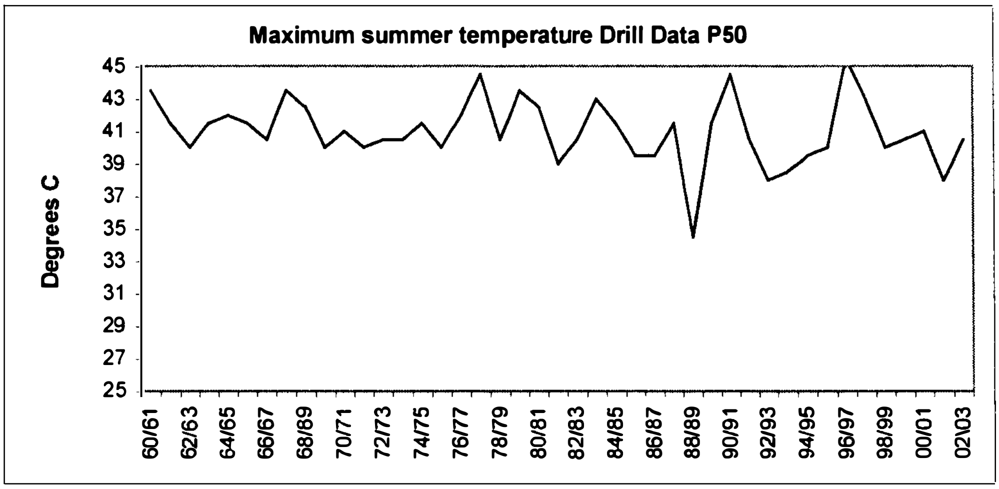
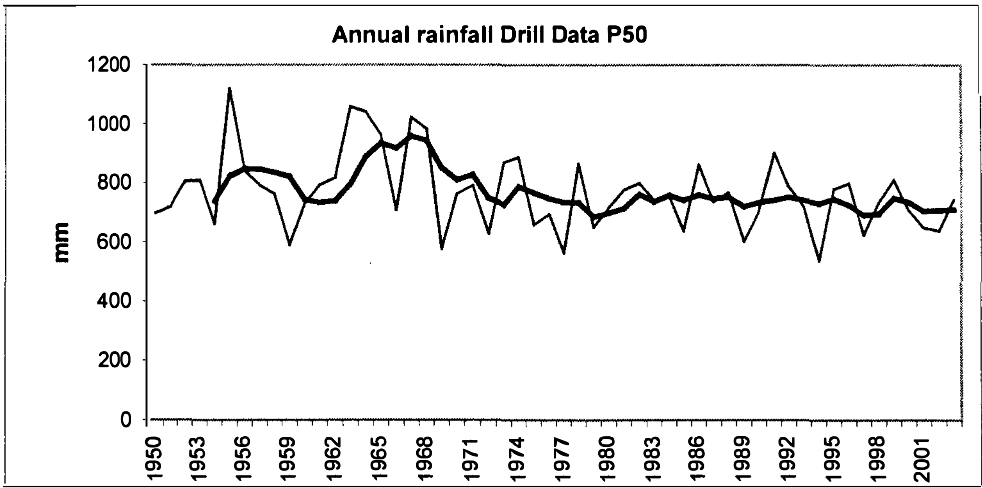


Figure 3.19 **a)** Drill Data P50, monthly maximum temperature. The data in drill data is modelled from surrounding weather location.
b) Drill Data P50, maximum summer (December to April) temperature. The data in drill data is modelled from surrounding weather locations.

a)



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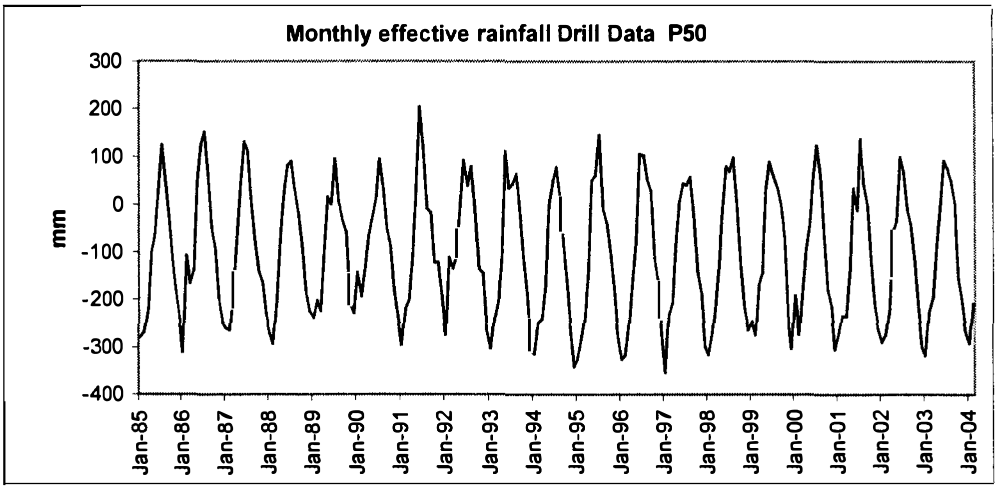


Figure 3.20 **a)** Drill Data P50, annual rainfall. The data in drill data is modelled from surrounding weather locations.
b) Drill Data P50, effective monthly rainfall. The data in drill data is modelled from surrounding weather locations.

3.4 Discussion

On the Swan Coastal Plain, groundwater levels and recharge are exclusively dependent on climatic variations and uptake by groundwater dependent environments and users (Sharma and Craig, 1989). Groundwater levels on the Gnangara Mound have been gradually declining since the 1970's due to changes in climatic trends, and an increased reliance on groundwater for public and private water supply by the Water and Rivers Commission (Davidson, 1995). This decline is associated with, and considered to be the primary trigger for the vegetation deaths surrounding the P50 production bore in 1991 (Groom, 2000).

The annual hydrological cycle observed at the P50 production bore is typical of the hydrology of Western Australia's Swan Coastal Plain, where the groundwater levels and recharge patterns are controlled by the seasonality and amount of rainfall received (Allen, 1981).

The production bore at P50 was built in late 1980's and fist commissioned in 1989 (Water Authority of Western Australia, 1992), as indicated in Figure 3.4. It was at this time that the drawdown event occurred as an increased external pressure was placed on this system. It was the combination of the regional long-term groundwater decline trends, a rapidly falling groundwater table caused by abstraction and changes in the climatic conditions that were all associated with the collapse in the *Banksia* woodland community during the 1990 to 1991 summer.

3.4.1 Hydrological and climatic patterns at P50, Neaves and Yeal Swamp prior to drawdown event.

It has been observed at P50, Neaves and Yeal Swamp that there is a gradual decrease in the watertable level preceding and following the drawdown event at the P50 production bore. Leading up to this drawdown event there was a decrease in the average annual rainfall and an increase in the average maximum summer temperature. It was this gradual climatic trend, combined with dry hot summers between 1988 and 1992, and an increasing depth to groundwater that placed an environmental stress on the plant community associated with the P50 production bore. This made it vulnerable to the collapse that was experienced due to abstraction.

The production bore at P50 was commissioned in 1989, and it was at this time that the drawdown event occurred due to an increased external pressure that was placed on this system (Water Authority of Western Australia, 1992). In the summer of 1990/1991 the Waters and River Commission observed the changes in the *Banksia* woodland surrounding the P50 production bore and decreased abstraction immediately (Figure 3.4). This allowed the recovery of the watertable to a level similar to that observed prior to the drawdown event. It appears that it was only by chance that the climatic conditions at P50 were unfavourable at the same time that the production bore was turned on, therefore, we do not know wether the same scenario would have occurred if rainfall proceeding the commencement of abstraction, had allowed sufficient recharge to occur.

The environmental conditions experienced at Neaves and Yeal Swamp were identical to those at the P50 production bore. However, these two vegetation transects did not have abstraction bores adjacent to them, therefore, were unaffected by a drawdown event. This was observed by examining the sites' hydrographic data and will be demonstrated in the chapter 5 through the vegetation characteristics at these sites.

3.4.2 Hydrological and climatic patterns at P50, Neaves and Yeal Swamp following the drawdown event.

After the Water and Rivers Commission stopped abstraction in 1991 the groundwater levels observed at the P50 production bore recovered. Although the annual rate of groundwater continued to decrease between 1992 and 1997 the characteristics in the seasonal variations observed were identical to those pre-drawdown. In 1997 another drawdown event had been observed due to the recommissioning of the P50 production bore. This drawdown event did not affect the vegetation in the same way as the earlier drawdown event had, because the vegetation at the site had changed significantly and had been replaced with more drought tolerant species as a direct result of the drawdown event in 1989.

The current trends at the P50 production bore appear to be returning to the trends observed throughout the Gnangara Mound. If the sudden groundwater decline episodes were removed from the P50 production bore's hydrograph, a constant pattern would be observed indicating a gradual change over time. The current status of the watertable at the P50 production bore is equivalent to the three P-veg monitoring bores. This indicates that the hydrological pattern that would be observable today if the drawdown event had not occurred, has not been lost from the system, and that the watertable has the potential to return to a similar state following a drawdown event.

Following 1990, the trends at Neaves and Yeal Swamp changed very little. The groundwater level decline observed, continued at a steady rate (Figure 3.9 and 3.10). The annual rate of decrease observed at Neaves post 1990 continued at the same rate to those observed prior to this data (Figure 3.12). After the increase in the groundwater level at Yeal Swamp between 1985 and 1989, the groundwater levels continued to decrease at a steady rate. The annual rate of decrease at Yeal Swamp also decreased at a steady rate and remained at about 10cm per month (Figure 3.12).

Constant monitoring of hydrological and climatic trends is required to determine any long or short-term changes in hydrology that may result in a sudden decline event. Reducing the impacts of drawdown on the native *Banksia* woodland vegetation surrounding groundwater production bores and wellfields is an important task for managers of groundwater resources. The understanding of such processes and events is essential for the maintenance of groundwater levels within limits necessary to support ecological water requirements (Groom et al., 2000). In the future, reducing or completely ceasing abstraction following years of poor recharge may reduce the risk of such a wide-scale disturbance event occurring in the future.

Chapter 4

Floristic changes and recovery in *Banksia* woodland community impacted by a sudden groundwater decline event.

4.1 Introduction

Water is considered to be the major limiting resource to plant growth and survival in regions with a Mediterranean-type climate, particularly during dry summer periods when low water potentials develop (Poole et al., 1981; Miller et al., 1983-84; Mooney and Miller, 1985; Stock et al., 1992). The Swan Coastal Plain is situated within this climatic region, and interactions between the climate, soils and geology has an important bearing on the water requirements of the associated *Banksia* woodlands (Dodd and Heddle, 1989).

Banksia woodlands are typically found in soils that consist of deep leached sands that have extremely low water holding capacity, and consequently, virtually no water is available in the top few metres of soil during the 5 to 6 dry months of the year. *Banksia* woodland communities in this situation rely completely on the groundwater that is located a few metres below the surface (Dodd and Heddle, 1989).

The Gnangara Mound is one of two large shallow unconfined aquifers on Western Australia's Swan Coastal Plain that is currently being used as part of the public metropolitan water supply (Groom et al., 2000). Groundwater abstraction for public water supply results in the lowering of the watertable, which has the potential to be detrimental to the *Banksia* communities that are reliant on this water supply (Allen, 1981). Groundwater abstraction from bores produces a 'cone of depression' within close proximity to the bore decreasing the watertable in this area. This impact on phreatophytic vegetation (groundwater dependent vegetation) depends on abstraction rates of individual bores and the number, location and spacing of these bores (Davidson, 1995). Vegetation is affected by sudden groundwater decline events when abstraction rates are high over a relatively short period of time, and recharge to the aquifers is slow due to changes in environmental conditions (Groom et al., 2000).

Much of the previous work that examined the changes in *Banksia* woodlands in association with groundwater variability described the relationship between *Banksias* and groundwater over a relatively long time period (Kite and Webster, 1989). Preceding studies in this area have investigated water relationships of representative species from *Banksia* woodland canopy and understorey plants, with the aim of documenting diurnal and seasonal variation. These studies also provided information on the relative importance of soil-stored moisture and groundwater to the water economy of a woodland community (Dodd and Bell, 1993). Most of these reports, although they are few in number, concluded that plant species within *Banksia* woodlands exhibit a variety of physiological responses to changes in groundwater availability (Holling, 1996). Results show that in many understorey plants the intensity of water stress is inversely related to rooting depth (Dodd and Bell, 1993). However, this has been proven to be untrue for *Banksia* woodland canopy species and certain deep-rooted groundwater dependent shrubs as they are reliant on groundwater levels, not soil moisture (Grieve, 1956).

Although the *Banksia* woodlands of the Swan Coastal Plain have been described in great detail in numerous vegetation surveys (Mattiske and Associates), there is little published information on *Banksia* woodland response to sudden groundwater decline events (Gibson et al., 1994). Those studies that have been completed examined the impact of groundwater abstraction on *Banksia* communities, and described the floristic changes that had resulted from sudden groundwater decline events and compared them to similar corresponding sites (Groom, 2000a). In particular, studies have been carried out comparing the response of deep-rooted phreatophytic vegetation with non-phreatophytic vegetation in a sudden groundwater decline event (Groom, 2000b). Results for these studies showed that dramatic changes in the floristic patterns of sites that experienced sudden groundwater decline event occurred (Groom et al., 2000c; Mattiske and Associates, 1988).

In the past it has been predicted that if trends seen on the Gnangara Mound were to continue, a shift in community composition towards the xerophytic end of species continuum would be observed (Havel, 1968; Muir, 1983). These changes would be most noticeable in the wetter lower lying areas of the Gnangara Mound, and would first be observable through a change in phreatophytic vegetation (Dodd et al., 1984).

Many of the vegetational changes likely to be associated with groundwater abstraction in *Banksia* woodlands have already been observed as a response to long-tern, regional changes in groundwater levels (Farrington and Bartle, 1991). These changes are predictable and have occurred over long periods as a response of *Banksia* woodlands to reduced water availability. It was the rapid change in groundwater levels caused by abstraction that resulted in the disturbance of the phreatophytic vegetation. The consequence of this disturbance to the groundwater was large-scale deaths within a *Banksia* woodland community, and it is the resilience of this woodland that needs to be examined (Groom et al., 2000).

The aim of this chapter is to examine the changes that have occurred in *Banksia* woodland communities that are associated with recovery from sudden groundwater decline events. A description of the recovery process associated with decline episodes was completed to gain an understanding into whether the vegetation at P50 demonstrates a high degree of resilience to sudden decline events. This was achieved through a series of comparisons and multivariate analyses.

4.2 Methods

4.2.1 Site Selection.

Vegetation characteristics and groundwater levels have been monitored (pre- and post impact) for 15 years, and were available from the Department of Environment for this project (Figure 4.1). The site P50 is an example of one of the most significant impacts of abstraction operations on native *Banksia* vegetation. In the summer of 1990 to 1991 the area surrounding this production bore suffered severe vegetation loss, where up to 80% of all *Banksia* trees died (Mattiske and Associates, 2000). This tree mortality was attributed to a rapid drawdown of the watertable as a result of increased summer abstraction (Kite and Webster, 1989) and decreased winter recharge at the site.

4.2.2 Historical Datasets.

The production bore known as P50 in the Pinjar borefield, is one of 15 bores that was established as part of a long-term vegetation-monitoring program (Table 4.1). These transects have been monitored every 2 to 4 years since their establishment and date back to 1966, when four transects (Neaves, South Kendall, Tick Flat and West Gironde) were established by Havel (1968), to provide ecological data to determine suitable sites for pine plantation establishment. Havel's four transects were remonitored in 1976 by Mattiske (nee Heddle) whilst working for the Western Australian Forestry Department (Heddle 1980), when it was decided that these four transects would provide useful data on the floristic composition on the Gnangara Mound prior to the commencement of public groundwater abstraction. Three of these transects are within close proximity (< 2 km) of production bores (Neaves, W Gironde, S Kendall, Table 4.1). The Tick Flat transect is >25 km from the nearest production bore. All four transects are monitored as part of the current vegetation monitoring program, except West Gironde which no longer exists as it was partially cleared for urban development in 1987.

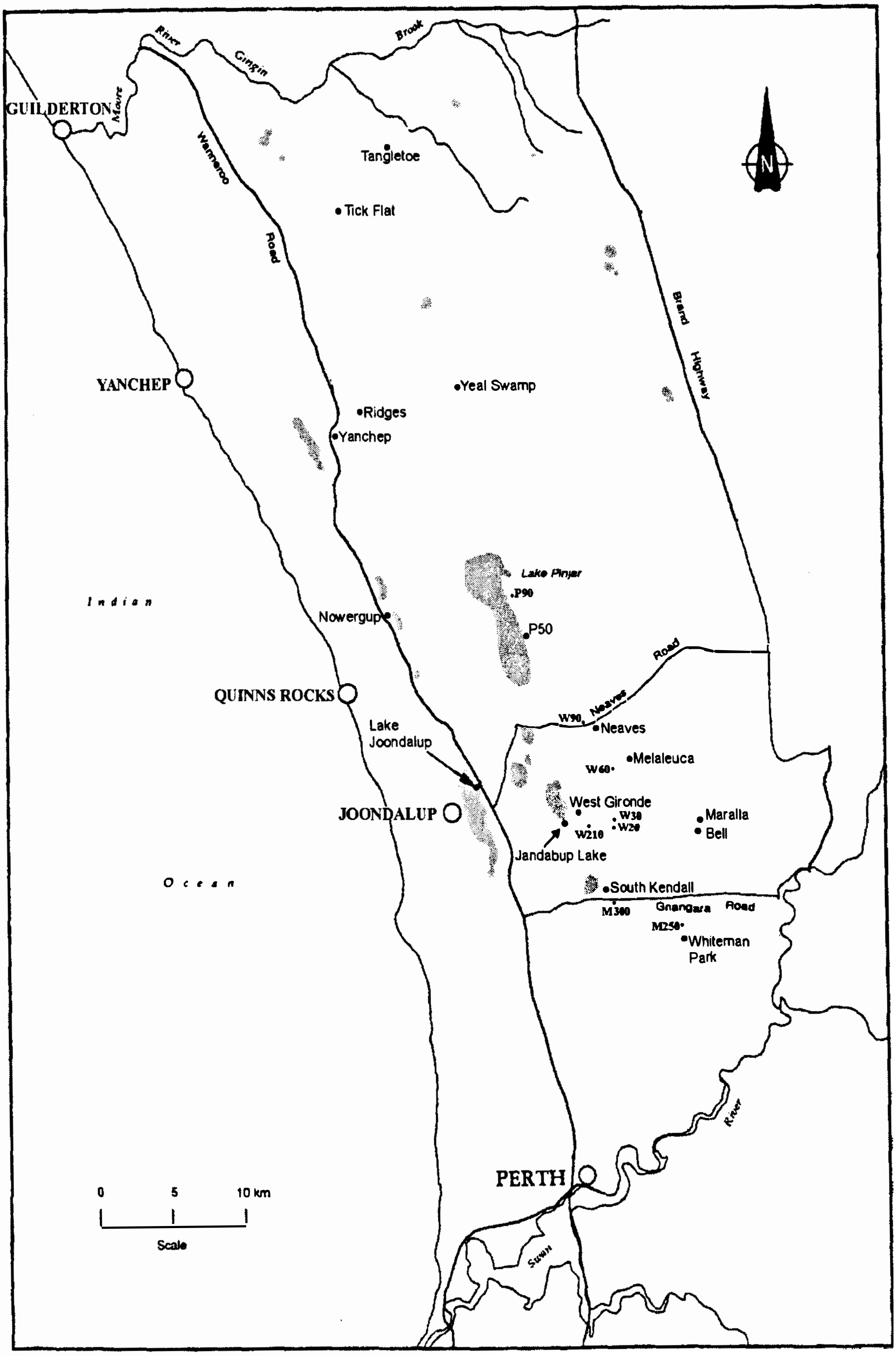


Figure 4.1 Location of monitored vegetation transects (large black dots) and closest groundwater abstraction bores (small black dots) on the Gnangara Mound (Mattiske and Associates, 1995).

In 1976 transects adjacent to Jandabup Lake and Lake Joondalup were established in response to concerns by the Water and Rivers Commission, about decreasing lake levels on the fringing native vegetation. Other transects (Nowergup, Ridges, Tangletoe, Yanchep and Yeal Swamp) were created in 1987 to include areas of the Gnangara Mound that were/are currently not under the influence of groundwater abstraction into the monitoring program (Table 4.2). A transect was established within close proximity (~50 m) from the Pinjar bore P50 in 1988. This transect was established prior to the commencement of groundwater abstraction from the bore to directly monitor changes in floristic structure and composition resulting from abstraction.

All transects occur within conservation reserves or on crown land, and were positioned along a topographical gradient starting at a localized depression and ending at a high point in the landscape, usually a dune crest. The transect at P50 was the exception due to its relatively flat landscape. Transects varied from 200 to 520m in length, and were subdivided into two parallel lines down the length of the transect. Each line was further subdivided into 20 x 20m plots for overstorey assessment. Within each of these were two 4 x 4m quadrats used to monitor the understorey (Figure 4.3).

Within each overstorey plot, the number of dead and alive plants for each species present was recorded. In addition, the diameter at breast height and the condition of all stems per tree was noted. The condition (vigour) of each stem was categorised as healthy, stressed or dead, primarily based on foliar characteristics. Within each understorey quadrat, the number of plants (alive and dead) for each species present was recorded, and where possible, percentage foliage cover. For species where the numbers of individuals were difficult to count accurately (i.e. grasses and herbaceous species), only their presence was noted. Vegetation assessments occurred in mid to late spring of the designated year (Mattiske, 2000).

For the purpose of this research, the data from the two longitudinal parallel lines that formed each transect was pooled because of the topographical and groundwater depth gradients exhibited by all transects. Thus, instead of using the data from two adjacent 20 x 20m plots along the same topographic position as separate entities, the data was combined to form one 20 x 40m plot (Figure 4.3). Therefore each 20 x 40m plot contained overstorey (obtained from combining the two 20 x 20 m plots) and understorey (obtained from combining four 4 x 4m quadrats) data.

Table 4.1 History of transect monitoring on the Gnangara Groundwater Mound. Transects were monitored in Sept-Oct of the designated year (Mattiske and Associates, 1995).

Transect	1966	76	78	80	81	84	87	88	90	91	93	96	99	02
Neaves	●	●	●	●	●	●	●		●		●	●	●	●
Tick Flat	●	●	●	●	●	●	●		●		●	●		●
South Kendall	●	●	●	●	●	●	●		●			●		
West Gironde	●	●	●	●	●	●	●		●					
Jandabup Lake		●	●	●	●	●	●		●		●		●	
Lake Joond		●	●	●	●	●	●		●					
Nowergup							●		●					
Ridges							●		●			●		
Tangletoe							●		●				●	●
Yanchep							●		●		●		●	●
Yeal Swamp							●		●		●	●		●
Gnangara P50								●		●	●	●	●	●
Whiteman Park										●		●	●	●
Bell												●	●	●
Maralla												●	●	
Melaleuca												●	●	●

Table 4.2 Distance of nearest groundwater production and monitoring bores to the centre of the vegetation monitoring transects (Mattiske and Associates, 1995).

Transect	Production bore	Distance (km)	Monitoring Bore	Distance (km)
Within close proximity to production bores (≤ 2 km)				
P50	P50	0.05	P50	0.05
Neaves	W90	1	WM6	0.2
W Gironde	W210	1.2	JB2	0.3
S Kendall	M300	1.3	MM9	0.4
Jandabup Lake	W210	2	JB12A	0.1
Whiteman Park	M250	0.8	MM26	0.8
Melaleuca	W60	1.9	NR12	0.6
Not near production bores (> 2 km)				
Lake Joondalup	W255	6.5	JP20B	0.7
Ridges	P90	12	GA3	1.2
Yanchep	P90	13	YN3	1.5
Yeal Swamp	P90	14.7	Y100	0.3
Tick Flat	P90	27	GA23	2.4
Lake Nowergup	P40	8	LN2/89	0.2
Bell	W20	5.9	PB2	0.3
Maralla	W30	6.5	L130C	0.3
Tangletoe	P90	30	-	-

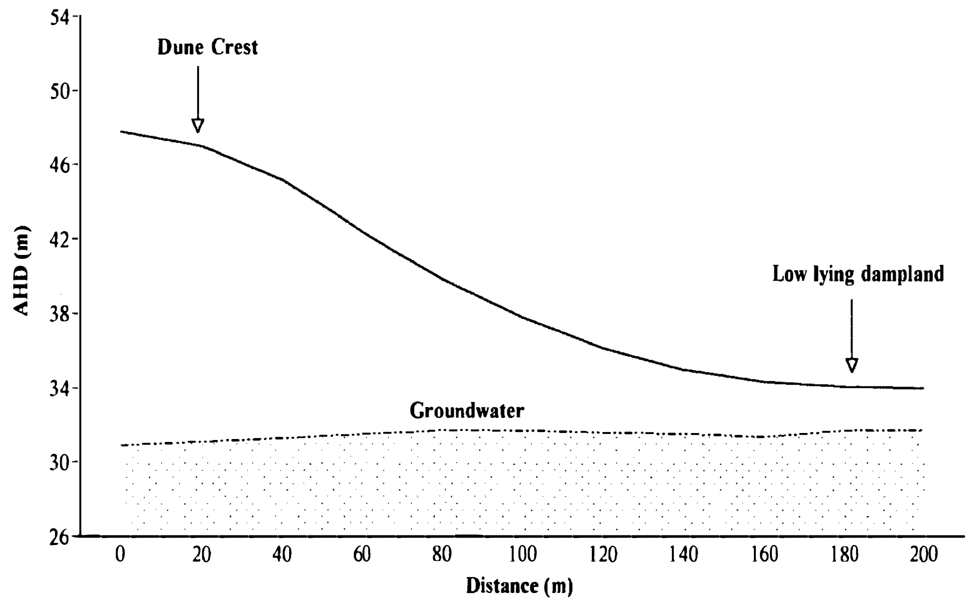


Figure 4.2 Typical topographical and groundwater profile of the vegetation transects (Mattiske and Associates, 1995).

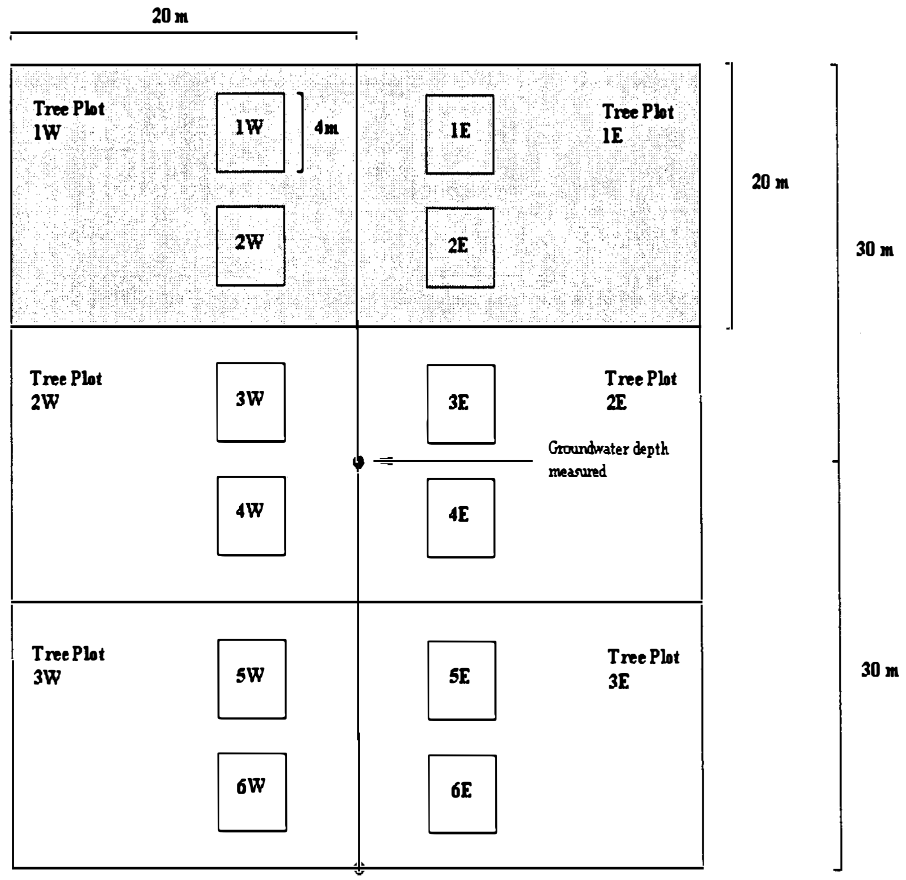


Figure 4.3 Typical layout of vegetation transect. This sequence of plots continues until the end of the transect. The shaded area represents the area used in this study to represent a single sampling unit (Mattiske and Associates, 1995).

Throughout the vegetation monitoring history, groundwater levels along transect have never been quantified. Hydrographs of the closest observation bores to the transects were obtained from Water and Rivers Commission as a means of determining the past hydrological regimes experienced within the region of each transect. Other factors (i.e. fire and rainfall [where rainfall influences groundwater recharge]) that may influence floristic changes on the Gnangara Mound were also investigated. The fire history of each transect was obtained from maps and microfiche records held by the Department of Conservation and Land Management, Western Australia.

4.2.3 Vegetation Assessment.

Current vegetation characteristics at P50 were assessed in spring/summer of 2003/2004 to compare with other current status sites. To assess current floristics at P50 this study replicated the methods employed in the historical monitoring program (Figure 4.3). Data at P50 was collected using the existing transect and following the protocols outlined by Mattiske (2000) in the historical data; i.e. transects were subdivided into two parallel lines that ran down the length of each transect, and each line was further divided into 20 x 20m plots for overstorey assessment, with two 4 x 4m quadrats inside the larger ones used to monitor the understorey (Figure 4.3). This 2003/2004 assessment could not be compared to Mattiske's historic data due to sampling biases.

Specifically, analysis of change in species composition (e.g. native vs. exotic), plant biodiversity (species richness), abundance (species site importance, cover), physiognomy (structural complexity) and function (grouping according to water requirements), were conducted. Water requirements were inferred by analysis of the species richness and abundance of two biologically important functional groups - life history traits and rooting patterns. Life history traits for each species occurring within the transects was categorized according to their longevity (annual, perennial), life form (tree, shrub, herb – includes grasses) and whether they were native or exotic. Rooting pattern categories were based on those described by Pate *et al.* (1984) for Western Australian sandplain species. The rooting pattern for each species was determined from published sources (Dodd *et al.* 1984), personal observations and consultation with Prof. John Pate of the Botany Department, University of Western Australia.

Within each overstorey plot the number of dead and alive plants for each species present was recorded. The condition of each stem was then categorised as one of the following; healthy, stressed or dead, based on foliar characteristics (health of foliage and stems). For each of the understorey quadrats, the number of plants for each species was recorded, and where possible, the foliar percentage cover for the species. For species where the number of individuals is difficult to count accurately (i.e. grasses and herbaceous species) their presence and percentage cover was noted.

Although the comparison of pre- and post vegetation characteristics could have been restricted by limitations in the historic dataset, sufficient information was available for P50 to allow assessments to be made.

4.2.4 Data Analysis.

The analysis of the historical and current datasets was made in several stages. Initially, graphical comparisons at P50 of each sample year were completed to compare the total number of species within transects over time, species richness over time and the percentage of exotic species over time. Multivariate analysis techniques (ordination and clustering) were then employed to ascertain composition similarity. Abundance data was used when examining changes in composition of overstorey or understorey species. Percentage frequency data was also used and refers to the number of times that a species occurs across the transect.

Non-metric multidimensional scaling (NMS) is an ordination technique that was employed to investigate multi-temporal patterns or floristic 'trajectories'. NMS uses a measure of similarity between sites, replacing the original species composition data by a matrix of similarity values, using this similarity matrix to obtain an ordination diagram. The Euclidean distance between points on the resulting ordination diagram can be used to compare relative changes in species composition between two sites (or monitoring dates). NMS is described in detail in Jongman *et al.* (1995), but in principle attempts to satisfy all the conditions imposed by the ranking of the similarity matrix, in a pre-specified number of dimensions. This is an iterative procedure, attempting to produce the 'best' ordination that represents the similarity matrix data as indicated by a stress value (ranges from 0 to 1). The lower the value (closer to 0) the better the representation. The Sørensen coefficient (also known as the Czekanowski or Bray-

Curtis coefficient) was also used as a measure of similarity, and applied to presence-absence and abundance data. In particular we were interested in relating changes over time between, and within, the plant communities. The similarity matrix produced for NMS can also be used as a similarity index (Kent and Coker, 1992).

Bray-Curtis similarity matrixes were completed for presence/absence, abundance and percentage frequency data. Analysis between samples was chosen and depending on whether the data was presence/absence, abundance or percentage frequency, the transformation selected was either presence/absence or square root. A MDS analysis was then completed producing an ordination representative of the dataset entered. 100 restarts were chosen as the number of restarts for the ordinations.

When completing comparisons between transects the data collected in 2003, by Broun, was not added to that collected by Mattiske and Associates to overcome sampling bias and observation errors. However this 2003 data was examined and compared to sites with no long-term monitoring history that were in close proximity to P50 as a means of obtaining current status information on *Banksia* woodlands surrounding P50.

4.3 Results

4.3.1 Hydrological pattern at P50.

P50's hydrological trends have been described in the previous chapter, and include the hydrological characteristics that have lead up to the sudden groundwater decline event, and the associated patterns preceding such an event that have aided in the recovery of this *Banksia* woodland. Therefore, they have not been included in this chapter.

4.3.2 Floristic attributes at P50.

4.3.2.1 P50 species floristics.

The transect at P50 comprises of twenty 20m x 40m plots that have been sampled every 3 to 5 years since establishment in 1988 (the year abstraction commenced). The vegetation found at P50 can be defined as a *Banksia attenuata* – *Banksia menziesii* woodland, consisting of an open overstorey defined by these two species, with a relatively complex understorey (Figure 4.6). A total of 87 plant species were found along the transect in 2002 and were spread across a number of families. The majority of the species found belong to following families: Myrtaceae, Proteaceae, Fabaceae, Cyperaceae, Poaceae, Mimosaceae, Stylidiaceae and Orchidaceae. Other families were also represented and consisted of species that are commonly found in *Banksia attenuata* – *Banksia menziesii* woodlands, within the Bassendean Sand Dune System.

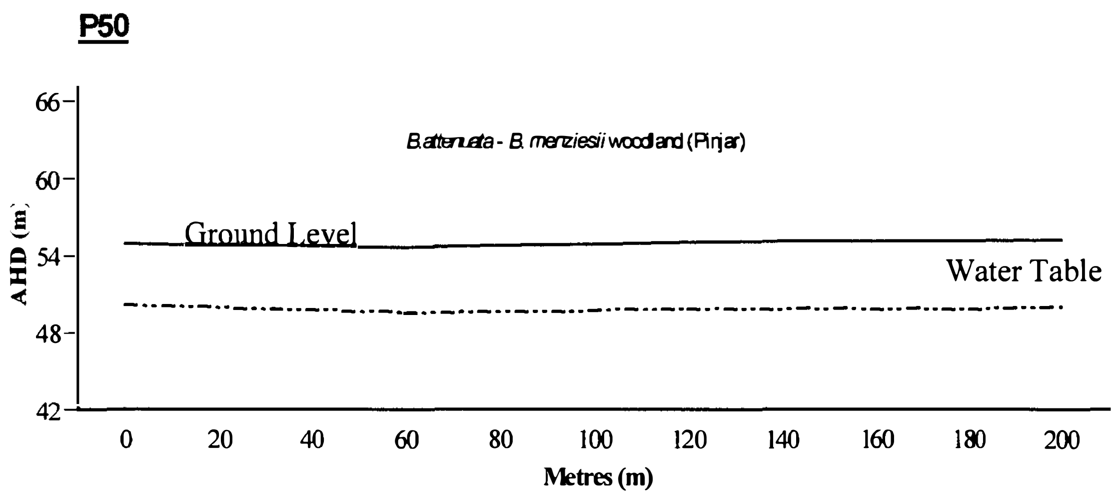


Figure 4.4 Transect at P50 showing length, ADH (m), and positioning of vegetation communities (Mattiske and Associates, 1995).

A number of species that were commonly observed along the length of the transect included the following: *Banksia attenuata, Banksia menziesii, Hypocalymma augustifolium, Stylidium brunonianum, Xanthorrhoea preissii, Actinotus glomeratus, Comesperma calymega, Conostephium pendulum, Damperia linearis, Leucopogon conostephioides, Stylidium repens, Adenanthos cygnorum, Eriostemon spicatus, Hibbertia helianthemoides, Tricoryne elatior, Verticordia nitens, Calytrix flavescens, Hibbertia subvaginata, Lobelia tenuior, Lomandra hermaphrodita, Lomandra sericea, Melaleuca seriata, Petrophile linearis, Drosera paleacea, Gonocarpus pithyoides, Lomandra preissii* and *Regelia ciliata.*

The dataset for P50 that contains a complete list of species is percentage frequency (Table 4.3). This list has been grouped according to the rooting categories and rooting patterns for each species, as defined by Dodd et al. (1984). The number of species found at P50 has decreased over time, and the trend in the quantative data supplied demonstrates a decline in the numbers and representation of the species over time (Table 4.3). This quantative data will be used later in this chapter to closely look at life history traits, MDS (Multidimensional Scaling), ordinations, diversity indices and correlations.

Most species at P50 belong in Dodd's shallow-rooted species category and specific changes in this category will be observable later in the chapter. Although the most obvious change at P50 following the drawdown induced vegetation collapse was in the overstorey, the percentage of species in Dodd's deep-rooted species category is relatively small compared to the shallow-rooted category (Table 4.3).

The following list refers to Table 4.3, and describes the rooting categories that were established by Dodd et al. (1984):

Rooting pattern codes based on categories listed in Dodd et al. (1984).

1)	Shallow fibrous roots (all monocots)
2)	Shallow, branched roots
3)	Deep sinker roots (insignificant laterals)
4a)	Shallow sinker root, significant laterals
4b)	Deep sinker roots, significant laterals
5)	Horizontal roots
6)	Shallow horizontal and vertical roots
7)	No roots present (stem parasites)

Table 4.3 % Frequency of plants occurring within the P50 transect.

Rooting depths are classified as shallow (<1m), medium (1<2m) and deep (>2m) and based on data from Dodd et al. (1984).

Species	Root Type	P50 1988	1993	1996	1999	2002
Non-rooting species						
Cassytha flava	7	5	0	5	0	0
Cassytha racemosa	7	2.5	0	0	0	0
Cassytha sp	7	0	0	2.5	0	0
Shallow-rooted species						
Actinotus glomeratus	2	40	67.5	60	52.5	30
Aira caryophyllea (1)	1	0	0	0	5	0
Alexgeorgea nitens	1	7.5	7.5	7.5	5	5
Amphipogan turbinatus	1	0	0	0	0	0
Angallis arvensis (1)	2	0	0	0	2.5	2.5
Anigozanthos humilis	1	0	5	2.5	7.5	12.5
Austrostipa compressa	1	0	0	2.5	10	0
Avena fatua (1)	1	0	0	2.5	0	0
Briza maxima (1)	1	0	0	0	15	12.5
Caladenia sp	1	0	10	0	0	2.5
Carpobrotus edulis	2	0	0	0	0	0
Chamaexeros serra	1	2.5	2.5	0	0	0
Conostylis juncea	1	12.5	15	5	12.5	20
Corynotheca micranta	1	0	0	2.5	0	0
Cyrtostylis sp	1	0	0	0	12.5	10
Damperia linearis	2	55	65	55	52.5	45
Dasypogon bromeliifolius	2	100	100	100	97.5	97.5
Desmocladus flexuosus	1	5	0	0	0	0
Drosera erythrorhiza	1	0	5	0	2.5	0
Drosera paleacea	1	2.5	10	25	32.5	15
Drosera sp	1	0	0	0	0	2.5
Drosera sp (climbing)	1	0	22.5	0	20	40
Ehrharta calycina (1)	1	0	0	0	0	0
Euphorbia peplus (1)	1	0	0	0	0	0
Gladiolus caryophyllaceus (1)	1	0	12.5	20	50	40
Gonocarpus cordiger	2	22.5	30	32.5	42.5	35
Haemodorum laxum	1	2.5	0	0	2.5	0
Haemodorum spicatum	1	0	2.5	5	17.5	5
Hyalosperma cotula	2	5	15	0	87.5	77.5
Hypochaeris glabra (1)	2	0	2.5	5	37.5	45
Hypolaena exsulca	1	80	72.5	77.5	62.5	47.5
Isolepis marginata (1)	2	0	0	0	10	5
Johnsonia acaulis	1	0	5	2.5	2.5	0
Laxmannia ramosa	1	2.5	5	2.5	5	2.5
Laxmannia squarrosa	1	0	0	0	0	2.5
Lepidosperma squamatum	1	2.5	25	47.5	37.5	32.5
Leporella fimbriata	1	0	0	0	2.5	0
Levenhookia stipitata	1	0	0	0	0	0
Lobelia alata	2	7.5	0	0	0	0
Lobelia tenuior	2	0	2.5	22.5	5	2.5
Lomandra caespitosa	1	0	0	2.5	0	0
Lomandra hermaphrodita	1	22.5	60	57.5	52.5	45
Lomandra preissii	1	0	32.5	25	15	10
Lomandra sericea	1	22.5	50	52.5	60	42.5
Lyginia barbata	1	77.5	72.5	80	70	65
Mesomelaena stygia	1	2.5	0	0	0	0
Mitrasacme paradoxa	2	0	0	0	0	0
Monotaxis occidentalis	1	17.5	5	2.5	7.5	0
Orchidaceae sp	1	0	0	0	0	2.5
Patersonia occidentalis	1	55	52.5	47.5	42.5	42.5
Phlebocarya ciliata	1	70	65	57.5	57.5	57.5
Phyllangium paradoxum	2	0	2.5	0	82.5	20
Pithocarpa pulchella	2	0	2.5	0	0	0
Plathytheca galioides	2	5	5	2.5	5	5
Podotheca chrysantha	2	0	2.5	0	40	37.5
Podotheca gnaphalioides	2	0	0	0	0	2.5
Schoenus curvifolius	1	2.5	2.5	2.5	0	2.5
Schoenus pedicellatus	1	62.5	62.5	60	52.5	52.5
Sonchus sp (1)	2	0	0	2.5	0	0
Stylidium brunonianum	2	42.5	47.5	57.5	55	47.5
Stylidium junceum	2	0	5	0	0	0

Stylidium macrocarpum	2	0	2.5	0	2.5	0
Stylidium piliferum	2	0	10	7.5	10	7.5
Stylidium repens	2	47.5	30	57.5	52.5	42.5
Stylidium schoenoides	2	2.5	0	0	2.5	2.5
Thysanotus multiflorus	1	5	0	0	0	0
Thysanotus patersonii	1	5	0	0	0	0
Thysanotus thyrsoideus	1	10	17.5	2.5	32.5	12.5
Trachymene pilosa	2	0	2.5	0	47.5	50
Tricoryne elatior	1	52.5	50	42.5	27.5	0
Ursinia anthemoides (1)	2	7.5	10	0	57.5	62.5
Waitzia suaveolens	2	0	0	0	0	0
Xanthosia huegelii	2	0	2.5	0	2.5	0
Xanthorrhoea gracilis	1	2.5	2.5	2.5	2.5	2.5
Xanthorrhoea preissii	1	75	75	77.5	77.5	75
Medium-rooted species						
Conostephium pendulum	6	55	52.5	50	47.5	47.5
Euchilopsis linearis	6	32.5	20	10	2.5	5
Hibbertia spicata	6	25	15	2.5	0	0
Leucopogon conostephioides	6	85	72.5	62.5	57.5	60
Leucopogon parviflorus	6	0	0	0	0	0
Leucopogon racemulosus	6	2.5	0	0	0	0
Leucopogon sprengelioides	6	37.5	20	15	10	2.5
Philotheca spicata	6	47.5	47.5	37.5	30	25
Unknown 1	6	0	0	0	0	0
Deep-rooted species						
Acacia barbinervis	4b	32.5	20	10	5	5
Adenanthos cygnorum	4b	25	22.5	37.5	25	30
Banksia attenuata	4b	100	100	100	100	100
Banksia ilicifolia	4b	100	100	100	100	100
Banksia menziesii	4b	100	100	100	100	100
Beaufortia elegens	4b	0	0	2.5	5	7.5
Bossiaea eriocarpa	4b	7.5	7.5	5	5	5
Calytrix flavescens	4b	52.5	55	55	45	42.5
Daviesia physodes	3	2.5	0	5	0	2.5
Eremaea pauciflora	4b	2.5	2.5	2.5	2.5	2.5
Eucalyptus todtiana	4b	0	0	0	0	5
Hibbertia huegleii	4b	2.5	0	0	0	0
Jacksonia densiflora	3	2.5	0	0	0	0
Jacksonia floribunda	3	22.5	12.5	7.5	7.5	7.5
Jacksonia sternbergiana	4b	0	0	0	0	0
Nuytsia floribunda	4b	5	10	7.5	7.5	15
Petrophile linearis	3	67.5	52.5	45	32.5	35
Scholtzia involucrata	4b	17.5	15	12.5	12.5	10
Verticordia drummondii	4b	20	15	12.5	15	10
Verticordia nitens	4b	40	30	30	25	27.5

(1) represents exotic species

4.3.2.2 P50 life history, rooting patterns and tree data.

The life history traits noted at P50, examine trends in native vs. exotic species, plant longevity and life forms (tree, shrub or herb) (Figures 4.5, 4.6 and 4.7). The life history traits demonstrated a slight increase in annuals and herbs across the transect over time. This increase was also observed for exotic species, which experienced a slight increase in numbers between 1988 and 2002. The total number of species has fluctuated very little over time, however, the composition of the species found at P50 has changed significantly (Figure 4.5 and table 4.3).

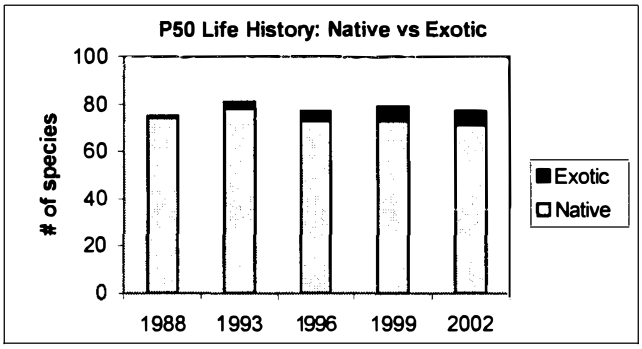


Figure 4.5 P50 Species richness over time. Highlighting - Life History: Total numbers of exotic and native species over time.

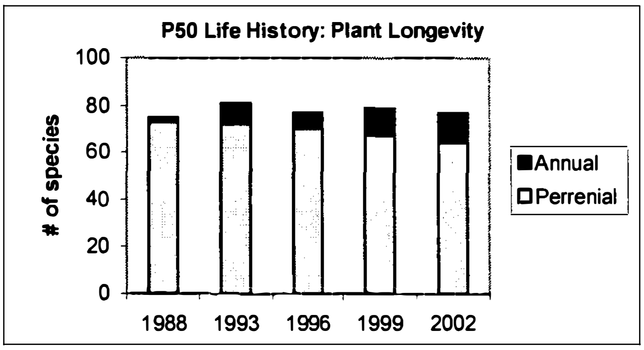


Figure 4.6 P50 Life History: Plant Longevity – Total number of annual and perennial species found at P50 over time.

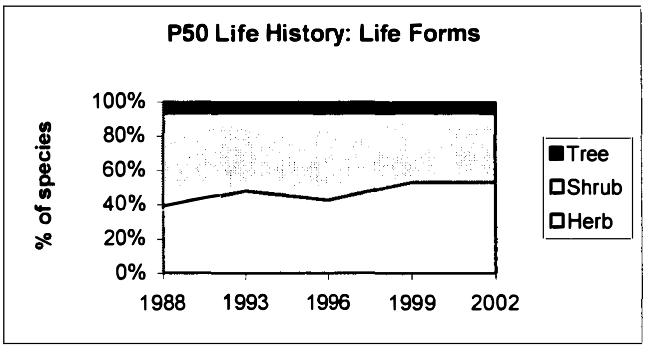
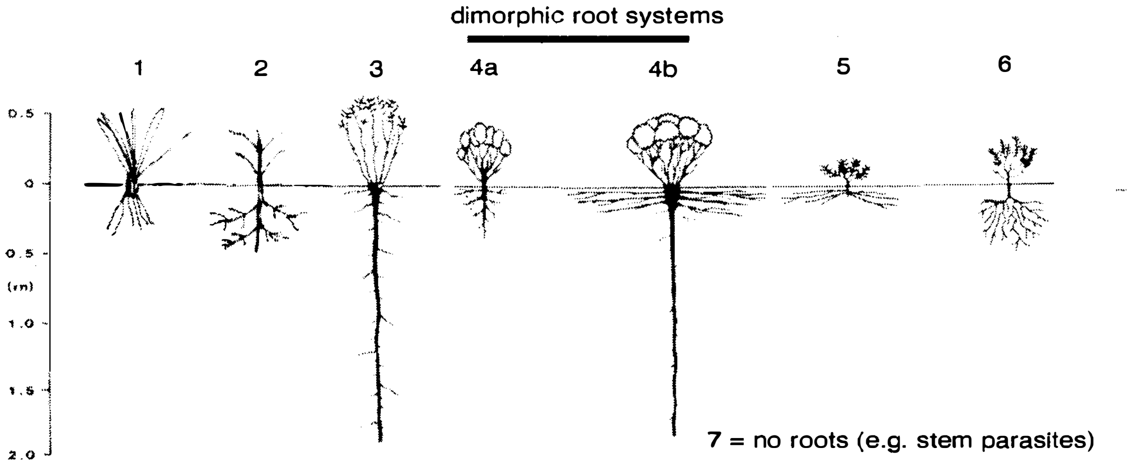


Figure 4.7 P50 Life History: Life Forms – Percentage of species found in varying life forms (Trees, Shrubs and Herbs (which includes grasses) over time at P50.

The initial increase in the number of exotic, annual and herb species post the drawdown event was observed in 1993. This observation was not unexpected as exotic weed species commonly invade native vegetation following a disturbance event (Figures 4.5, 4.6 and 4.7).

The percentage of tree species at P50 has changed very little over time, however, the percentage of shrub species has never fully recovered to pre-groundwater decline levels, even though it has fluctuated. The shrub species not represented today appear to have been replaced by herbaceous species, some of which are native and others exotic (Figure 4.7).

In addition to studying the life history traits as a way of examining the floristic patterns at P50, the rooting patterns were also categorized and graphed according to Dodd et al. (1984) (Figure 4.8). The rooting data has then been categorised into simpler categories to show the more general and obvious trends within the rooting types. These four categories include; non-rooting species (those species which are parasitic), shallow-rooted species (<1m), medium-rooted species (1-2m) and deep-rooted species (>2m). These categories can be observed in Table 4.3.



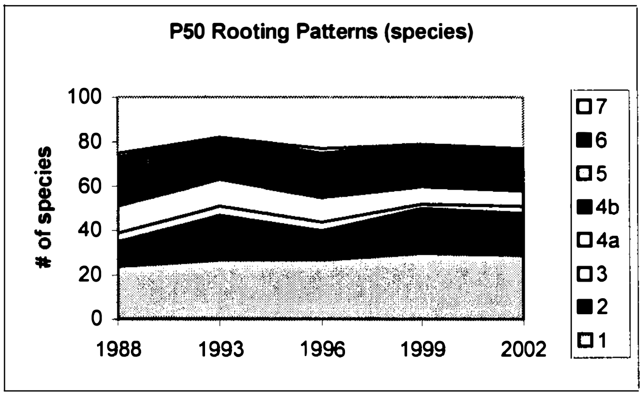
Rooting pattern notes (extracts from Pate *et al.* 1984)	
Types 1 and 2	These rooting patterns mainly occur in monocotyledonous families, where the root system of adult plants is largely, if not entirely, of adventitious origin, as well as in predominately herbaceous plant of other families.
Type 3	Tap-rooted plants are most common in the Fabaceae and Goodeniaceae.
Type 4	The vertical and horizontal root morphology type occurs predominately in woody genera. It is especially well displayed in the families Myrtaceae, Proteaceae, Fabaceae and Epacridaceae.
Type 5	Root systems with only shallow horizontal main roots are only occasionally expressed by the larger families, though universal among species of root hemi-parasites. This type of root is very rare among herbaceous species, and, in woody species, is often associated with a capacity to develop root suckers.
Type 6	This type involves stout woody roots with branches neither predominately vertical nor horizontal, and is highly infrequent, though present.
Type 7	Stem parasites.

Figure 4.8 Rooting patterns of the Swan Coastal Plain. Modified from Dodd *et al.* (1984) and Pate *et al.* (1984). Rooting pattern numbers as used by Pate *et al.* (1984), with Type 4 (dimorphic rooting pattern) divided into shallow and deep-rooted species.

There are three major changes within the rooting pattern at P50, on a species level (Figure 4.9a). The number of species noted in the shallow fibrous rooted plants increase slightly. The number of plant species increased over time at a rate of approximately 1 species every three years. An increase in the shallow branched rooted plant species was also observed, with a doubling of the number of species found in this category between 1988 and 2002. Although the above two changes indicate an increase in plant species, rooting type 4a (those species with shallow sinker roots with significant laterals) exhibits a decrease in the total number of species.

At a quantative level, the abundances of plants found within rooting types displayed a decreasing trend in the total number of plants observed across the transect (Figure 4.9b). This was represented across all rooting types. The most evident and expected observations were recorded in the deeper-rooted categories 4a and 4b. The reason why a decrease in the total abundance of species in these two categories would be expected, is that with sudden changes in groundwater the deeper groundwater dependent species have no time to adapt to rapid changes, therefore, these species died or became severely stressed due to lack of water. These species have a tendency to be larger, slower growing species, and take a relatively long time to adapt to change or to recover.

a)



b)

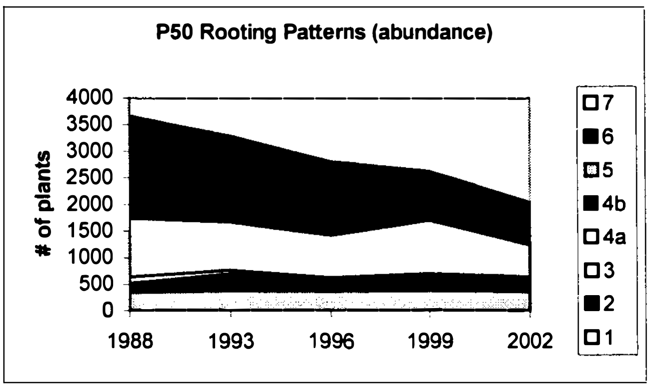
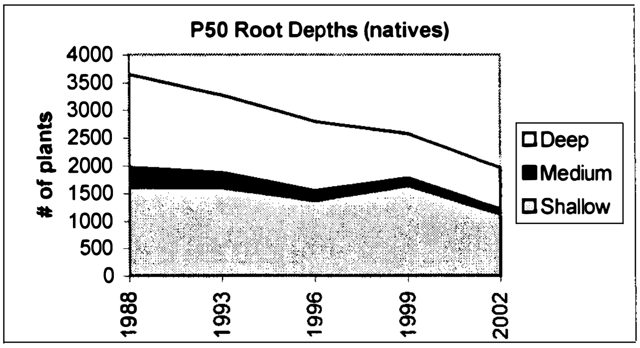


Figure 4.9 **a)** P50 Rooting Patterns over time. The graph displays how the rooting patterns of the plant species found at P50 has changed over time, using total number of species found within each rooting type over time.
b) P50 Rooting Patterns over time. The graph displays how the rooting patterns of the plant species found at P50 has changed over time, using total numbers of plants found within each rooting type over time.

The total abundance of plants in the various rooting depth categories made up by exotics was relatively small compared to the total number of natives (Figure 4.10). The general trend noted in the rooting depth categories (Figure 4.10) was similar to the trend observed in the rooting pattern graphs above, where there was a distinct decrease in total plant abundance over time (Figure 4.9b).

Through the comparison of data from 1988 to 2002, it was observed that the total abundance of plants in the medium-rooted and shallow-rooted categories remained relatively stable and continued to be well represented. However, in the deep-rooted species category the trends observed change significantly over time. In 2002 the total abundance of deep-rooted species had decreased, with approximately half the number of species in this year compared to 1988.

a)



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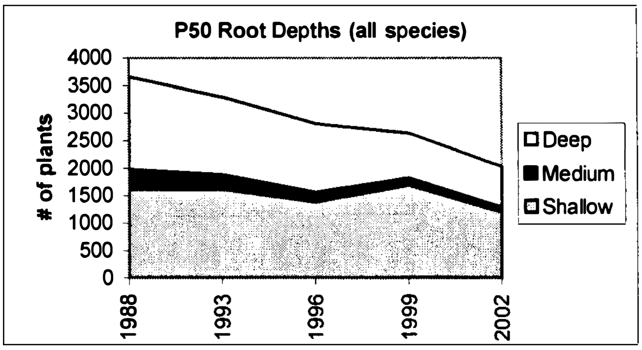


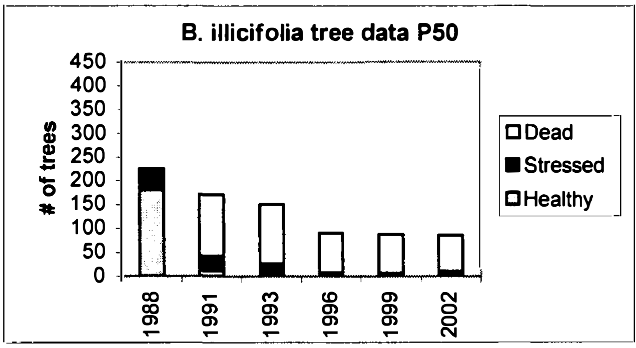
Figure 4.10 **a)** P50 Rooting Depths over time. Rooting depths are classified as shallow (<1m), medium (1<2m) and deep (>2m), and based on data from Dodd et al (1984). Natives only.
b) P50 Rooting Depths over time. Rooting depths are classified as shallow (<1m), medium (1<2m) and deep (>2m), and based on data from Dodd et al (1984). All species (natives and exotics).

The three main tree species observed at P50 were *Banksia attenuata, Banksia illicifolia* and *Banksia menziesii. Banksia ilicifolia* is usually located in the middle to lower slopes and depressions where depth to groundwater is relatively low. The other two species, *Banksia attenuata* and *Banksia menziesii* can tolerate a greater range in conditions, therefore, they have a greater ability to adapt to a changing hydrological regime, if time permits them to (Allen, 1981). The vigour of overstorey trees found at P50 has been identified as healthy, stressed or dead, and indicated how the phreatophytic *Banksia* vegetation at this site has responded to a large groundwater drawdown event.

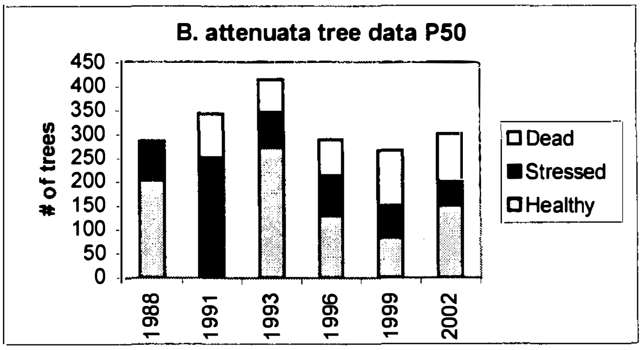
Changes in the vigour of all three *Banksia* species at P50 have been significant (Figure 4.11). The most observable and dramatic change occurred in 1991 where a 70 percent, 60 percent and 90 percent decline in healthy individuals of *Banksia ilicifolia, Banksia attenuata* and *Banksia menziesii* was observed. Groundwater abstraction had commenced at P50 just prior to these changes in the overstorey and they can be attributed to this event.

Since the decline in vigour that had been detected in 1991, *Banksia ilicifolia* had experienced minimal re-establishment across the transect and the few individuals that remained were very stressed, with poor vigour and growth. However, both *Banksia attenuata* and *Banksia menziesii* have recovered to some degree, demonstrating increase in vigour and establishment in 1993. Various fluctuations in vigour between 1996 and 2002 have been observed for *Banksia attenuata* and *Banksia menziesii. Banksia attenuata* has recovered better than *Banksia menziesii* over this time period, however *Banksia attenuata* was, and is, the dominant overstorey species (Figure 4.11).

a)



b)



c)

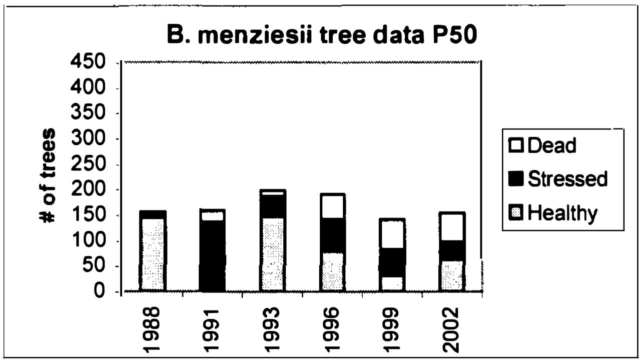


Figure 4.11 **a)** Changes in abundance adult vigour for *Banksia ilicifolia* at P50 1988 - 2002.
b) Changes in abundance adult vigour for *Banksia attenuata* at P50 1988 - 2002.
c) Changes in abundance adult vigour for *Banksia menziesii* at P50 1988 - 2002.

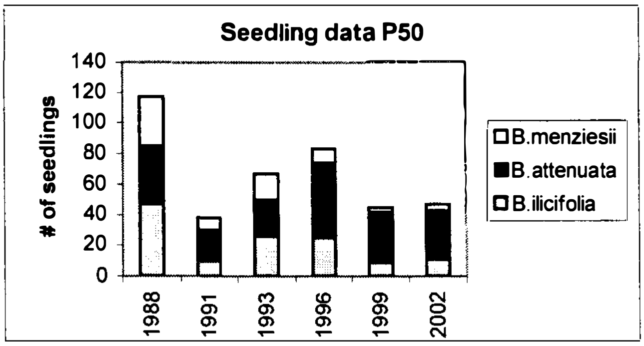


Figure 4.12 Changes in seedling abundance for *Banksia illicifolia, Banksia attenuata* and *Banksia menziesii* at p50 1988 - 2002

Seedling abundances at P50 between 1988 and 2002 demonstrated the same trends as those represented in tree vigour (Figure 4.12). There was an obvious decline in seedling abundance in 1991 for all tree species, however, since that date the numbers have fluctuated and have never fully recovered. The numbers of *Banksia attenuata* seedlings dominated those observed, with a decline in the number of *Banksia menziesii* seedling numbers noted. The numbers of *Banksia illicifolia* seedlings initially recovered following the drawdown event, but decreased in 1999 and remained low since.

4.3.2.3 Indicator species (Havel, 1968).

Havel (1968) described and identified a number of plants as indicator species for the status of a plant community along a spectrum of tolerance to water availability. He divided these indicator species into overstorey and understorey species so the observer could identify the trends in the vegetation, and determine the degree of tolerance to water availability. The following Figure (4.13) is the key designed by Havel to determine where on the spectrum that a particular plant community exists:

<u>Havel (1968) tree and shrub category classification.</u>

Tree Species Categories:

- 1a) Species tolerant of excessive wetness.
- 1b) Species of optimum moist sites, intolerant of extremes in moisture conditions.
- 1c) Species with a wide tolerance, but with maximum development on dry sites.
- 1d) Species without clear-cut site preference.

Shrub Species Categories:

- 2a) Species tolerant of excessive wetness.
- 2b) Species of optimum moist sites.
- 2c) Species with maximum development on dry sites.
- 2d) Species without clear-cut site preference.

Figure 4.13 Havel's (1968) indicator species for tolerance to water availability.

The indicator species defined by Havel showed the make-up of P50's species in regards to water tolerance. Species with maximum development on dry sites were observed to be the most dominant category (Table 4.4). The category with the second highest number of indicator species were those species that do not have clear-cut site preference. The vegetation described by Havel for the Gnangara Mound, indicated that the species present were dominated by xeric species and that Havel (1968) was suggesting a shift in the trends on the Gnangara Mound to this end of the floristic continuum.

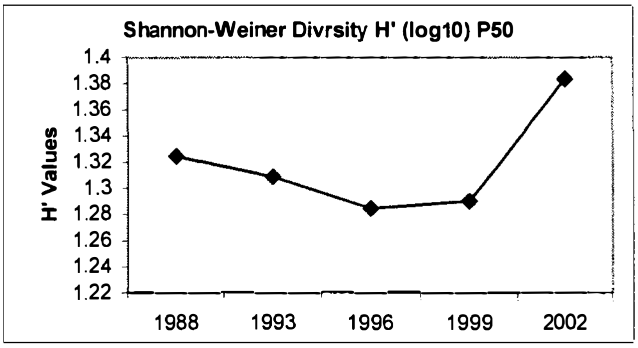
Table 4.4 Havel's Species Categories (1968)
Categorising species in relation to site preference.
Indicator Species highlighted in table.
Data in % Frequency.

Species	Root Type	1988	1993	P50 1996	1999	2002
Tree Species						
Species of optimum moist sites						
Banksia ilicifolia	4b	100	100	100	100	100
Species with a wide tolerance, but with max development on dry sites						
Banksia attenuata	4b	100	100	100	100	100
Banksia menziesii	4b	100	100	100	100	100
Species without clear cur site preference						
Eucalyptus todtiana	4b	0	0	0	0	5
Nuytsia floribunda	4b	5	10	7.5	7.5	15
Understorey Species						
Species tolerant of excessive wetness						
Euchilopsis linearis	6	32.5	20	10	2.5	5
Species of optimum moist sites						
Dasypogon bromeliifolius	2	100	100	100	97.5	97.5
Phlebocarya ciliata	1	70	65	57.5	57.5	57.5
Xanthorrhoea preissii	1	75	75	77.5	77.5	75
Species with max development on dry sites						
Beaufortia elegens	4b	0	0	2.5	5	7.5
Leucopogon conostephioides	6	85	72.5	62.5	57.5	60
Scholtzia involucrata	4b	17.5	15	12.5	12.5	10
Eremaea pauciflora	4b	2.5	2.5	2.5	2.5	2.5
Jacksonia floribunda	3	22.5	12.5	7.5	7.5	7.5
Species without clear-cut site preference						
Conostephium pendulum	6	55	52.5	50	47.5	47.5
Bossiaea eriocarpa	4b	7.5	7.5	5	5	5
Calytrix flavescens	4b	52.5	55	55	45	42.5

4.3.2.4 Data analysis of P50.

To study the change in the *Banksia* woodland at P50 over time, a number of data analysis techniques were implemented. A diversity index known as the Shannon-Weiner Diversity Index (also known as the Czekanowski or Bray-Curtis Coefficient) was used to access the diversity at P50. This change in diversity is measured as an H' (log10) value to show how the diversity has changed over time, and also a J' value which demonstrates the evenness of diversity and distribution within the transect.

a)



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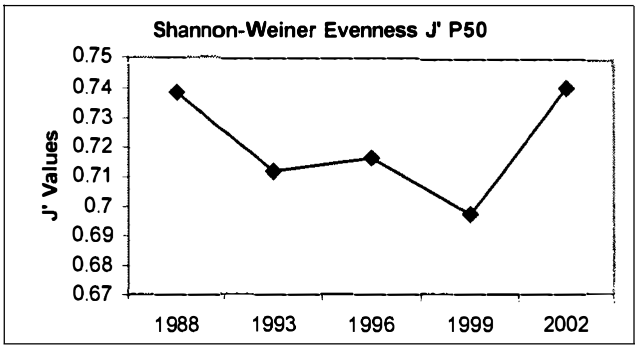


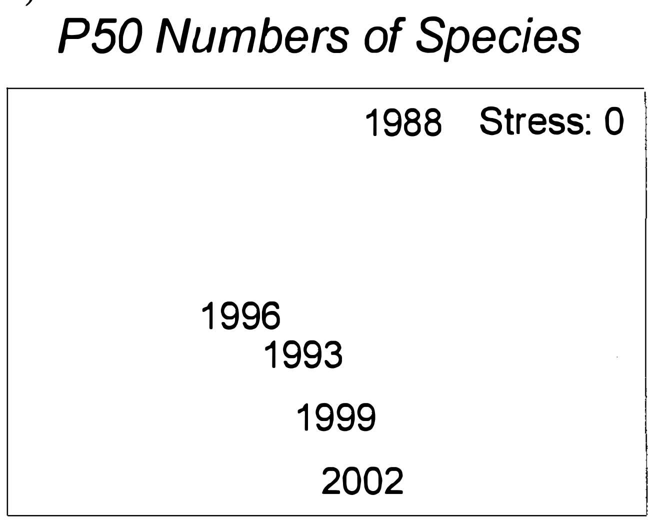
Figure 4.14 **a)** Shannon-Weiner Diversity Index H' (log10).
b) Shannon-Weiner Evenness Index J'. This Index shows how evenly the species are distributed within the transect over time. The higher the value the greater the diversity and the more even the distribution of the species.

It can be observed that the diversity at P50 has decreased between the years 1988 to 1996 at a steady rate and then gradually increased between 1996 and 1999. A rapid increase in the diversity between 1999 and 2002 was observed through a sharp increase in the Shannon-Weiner Diversity curve. This demonstrated that the diversity at P50 is currently increasing over time and is more diverse than it was pre-impact in 1988 (Figure 4.14a).

The relationship between diversity and evenness indicated that between 1988 and 1999 a trend developed with a gradual decrease in diversity and distribution (evenness) of species across the transect at P50. However, between the years 1999 and 2002 there is a fairly rapid increase in the diversity of species and the distribution of species throughout the transect. This demonstrates that the species found at P50 were more evenly distributed across the transect in 2002. The decrease in diversity and evenness at P50 in 1993 can be associated to the drawdown event, and the continued decrease until 1996/1999 attributed to the recovery time of the *Banksia* woodland community.

Non-metric multidimensional scaling (MDS), an ordination technique, was also employed to investigate multi-temporal patterns or floristic 'trajectories'. MDS uses a measure of similarity between sites, replacing the original species composition data by a matrix of similarity values, using this similarity matrix to obtain an ordination diagram. The Euclidean distance between points on the resulting ordination diagram was then used to compare relative changes in species composition between monitoring dates at P50.

a)



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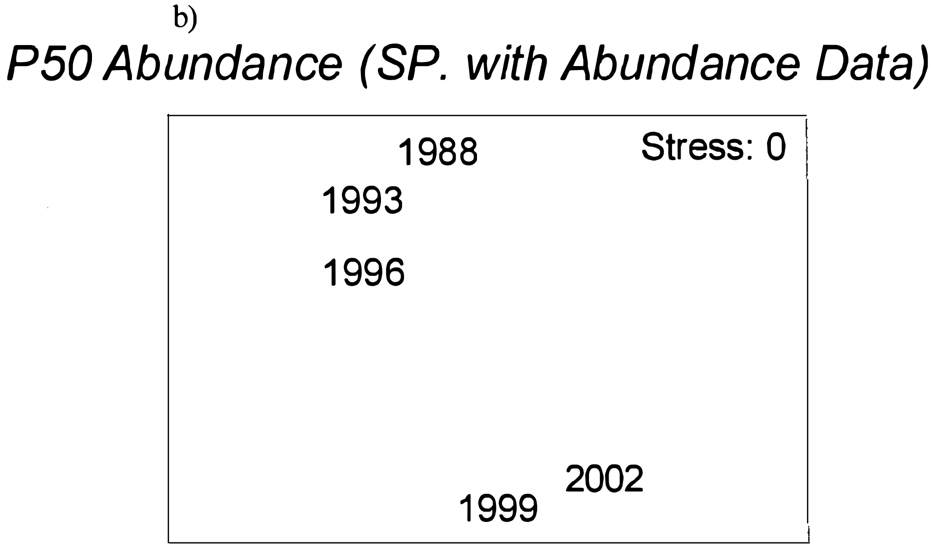


Figure 4.15 Bray-Curtis Similarity Matrix at P50 over time (MDS).

a) Data based on presence and absence data at P50 over time, demonstrating the change across the transect over time, based on the species found throughout the whole transect. Includes all species

b) Data based on abundance data at P50 over time, demonstrating the change across the transect based on the species abundance found throughout the whole transect. Only for those species that have abundance data.

c) Data based on % frequency data at p50 over time. Demonstrating the changes across the transect based on the species % frequency found throughout the whole transect. Includes all species.

c)

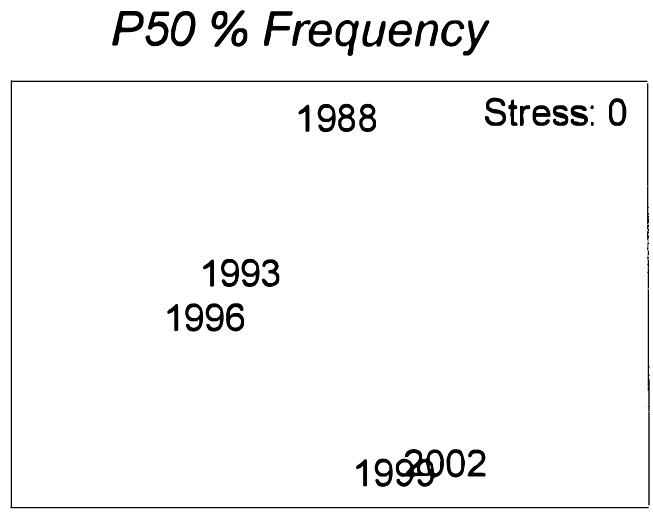


Figure 4.15 Bray-Curtis Similarity Matrix at P50 over time (MDS).

a) Data based on presence and absence data at P50 over time, demonstrating the change across the transect over time, based on the species found throughout the whole transect. Includes all species

b) Data based on abundance data at P50 over time, demonstrating the change across the transect based on the species abundance found throughout the whole transect. Only for those species that have abundance data.

c) Data based on % frequency data at p50 over time. Demonstrating the changes across the transect based on the species % frequency found throughout the whole transect. Includes all species.

The data in the above figure demonstrates the differences between each of the sampling dates presented in an ordination matrix. Across all of the three MDSs there was a one-way trend that had developed representing a directional change away from its original state. It was also observable that the stress factor for these three ordinations was equal to zero, meaning that the data was represented in the best possible way by the matrix (Figure 4.15).

The trend in these ordinations showed that P50, as a transect, has changed over time resulting in different species composition, species abundance and percentage frequencies of species throughout the transect. The species ordination matrix demonstrated that the make up of species over time has slowly changed, and that some of the species observed in 1988 are different to those observed in 2002. A large Euclidean distance on the species ordination between 1988 and 1993 represented a large change in the composition of species following the draw down event (Figure 4.15a).

The abundance ordination (for those species with abundance data) also represented this directional change over time. However, the Euclidean distance between 1988 and 1993 was smaller than that seen in the species ordination. The largest Euclidean distance was observed between 1996 and 1999 demonstrating a distinct change in the abundance of species during this period (Figure 4.15b). This was due to an increase in the number of a few smaller herbaceous annual species that were present in 1999. These same species were not as abundant in 1996.

Percentage frequency data contained all species found at P50, and the trends noted above were seen in this ordination matrix (Figure 4.15c). It was these clear changes that displayed not only the directional change that has occurred across the transect at P50, but the year-to-year changes in the transect as well. The large Euclidean distance between 1996 and 1999 was a result of the above-mentioned differences in floristics.

4.4 Discussion

The vegetation on the Gnangara Groundwater Mound is a complex band of vegetation types, the composition of which is determined by soil conditions, position within the landscape (topography), groundwater depth and soil moisture availability. The Gnangara Mound supports many varieties of plant communities and species, with the overstorey being dominated by *Banksia, Eucalyptus and Melaleuca* species. Monitoring of the P50 vegetation transects on the Mound over a 15-year period has shown that the floristic composition is continually changing. For this transect, fluctuations in the herbaceous species make-up has dominated the observations in the floristical changes seen. This is particularly in the native perennial and annual herbs, and exotic annual herbs. These species are non-phreatophytic, and are predominately grass species that possess fibrous shallow root systems.

Although *Banksia* woodlands may appear to be simple in structure and outwardly homogeneous in appearance they are not generally so, as they are usually floristically rich and taxonomically diverse (Havel, 1968). Even though we have only discussed one long-term monitoring transect in this chapter, the diversity in *Banksia* woodlands will become more apparent in the following chapter.

The floristic changes observed within the vegetation transects at P50 suggests that there is a general trend showing a decrease in all data types (species richness, abundance and percentage frequency) throughout the region, with the most significant changes occurring after the sudden decline event in 1988. The sudden change in the vegetation transect at the time of the drawdown event was expected, however, post this event the data indicated that floristically there is a variation in the transect with a trend heading in a one-way direction away from its original state in 1988. This trend is one of the characteristics that we were looking for to examine whether the site (P50) has recovered to pre-drawdown floristic status, both compositionally and functionally. From these observations, it appears that the floristics at P50 have changed over time, and whether these changes are a result of the drawdown event or other influential factors will be discussed in the following chapter by observing changes in other long-term monitoring transects.

Aplin (1976) suggested that in response to decreasing groundwater levels, shrub species known to tolerate periods of excessive wetness would be replaced by more drought tolerant species. These species may, in turn, be replaced by even more drought tolerant species (species that occur mainly on dry sites). This shift towards the 'xeric end of the floristic continuum' has been mentioned by Mattiske and Associates (1982-1997) when discussing changes in the vegetation composition and structure on the Gnangara Groundwater Mound. This interpretation ultimately relies on data collected by Havel (1968) on the habitat preferences of 42 tree and shrub species from the Bassendean Dune System, which have been identified and characterised as indicator species previously.

This classification by Havel (1968) of plant species into indicator groups demonstrates how a community is structured in terms of its reliance on water availability. At P50, the idea put forward by Aplin (1976) is supported, as the species at this site have shifted to the xeric end of the scale under reduced water availability. All data examined points to this shift in species tolerance to water availability. For example, the loss or reduction of *Banksia ilicifolia* (species categorised as tolerant of excessive wetness by Havel) from P50 and the gradual replacement of this species with more drought tolerant ones supports this trend. Similarly shrub species 'tolerant of excessive wetness' (e.g. *Astartea fascicularis, Pericalymma ellipticum*) have shown significant reductions in population size over the years of monitoring. However, using changing population size of these shrub species to indicate the occurrence of drawdown events is limited to areas of relatively shallow groundwater depths. This is because of their overall shallow root system (< 1m). At deeper groundwater depths, the population responses may result from decreasing shallow soil moisture levels (Mattiske and Associates, 1986). It cannot, however, be said with any certainty whether the observed population downsizing is directly attributable to groundwater drawdown, particularly for shallow-rooted species. For these species loss of individuals may be due to decreasing levels of soil moisture, resulting from extended periods of below average rainfall.

Rooting patterns over time also demonstrated the trend mentioned above, where there has been a decrease in those species that are suited to wet sites and a reduction particularly in deep rooted plants abundances has been observed. This reduction is significant as it defines the pattern occurring at P50 throughout its monitored history.

The degree of floristic variation found at P50 has specific implications for conservation, since adequate conservation requires that the range of variation should be represented in reserves (Dodd and Griffin, 1989). Because *Banksia* woodlands are so diverse this representation would be very difficult. As demonstrated in chapter 3, groundwater levels at P50 transect have declined significantly since 1988 when the transect was first monitored. It is this decrease over time and the rapid drawdown at P50 in 1989 and the coinciding years of low rainfall and recharge that appear to be responsible for the major floristic changes at this site.

This chapter has identified the floristic changes and recovery of a *Banksia* woodland community affected by a sudden decline event. It clearly demonstrated that there has been a decrease in all aspects of the floristic patterns observed along the transect, and that this is closely related to a decline in the groundwater level across the area as a whole. The following chapter will examine the resilience of *Banksia* woodland communities to a sudden decline episode, by comparing P50 to other short and long-term monitored vegetation transects.

Chapter 5

Resilience of *Banksia* woodland communities to sudden groundwater decline episodes.

5.1 Introduction

All ecosystems require water to maintain their ecological processes and associated communities of plants and animals. Throughout Western Australia, increasing pressure from consumptive uses has led to the review of the role that groundwater plays in controlling the health of major ecosystems. To ensure the continued health of these ecosystems the respective needs of the principle users of groundwater, that is groundwater-dependent ecosystems, need to be formally recognised and provided for. Determining water needs (water requirements) for an ecosystem involves identifying those aspects of the natural water regime that are most important for maintaining key ecosystem features and processes (Froend and Zencich, 2001).

The Gnangara Mound is one of Perth's largest underground aquifers and it provides a high proportion of Perth's public water, making this a very valuable resource. Large stands of phreatophytic Banksia woodland, however, are scattered throughout the area and are reliant on maintained groundwater levels. The dominant form of vegetation in the area is open Banksia woodland. Many of these areas of Banksia woodland have been cleared for urban and rural development, which is why remnants such as those on the Gnangara Mound are considered to be regionally significant (Water Authority Of Western Australia, 1995).

The impact and consequence of groundwater drawdown on phreatophytic vegetation ranges from gradual changes in community composition over decades, to sudden and extensive vegetation deaths (Groom, Froend and Mattiske, 2000a). Gradual changes in Banksia woodlands due to reduced soil water availability occurred over a relatively long period of time and a gradual change in species composition and community structure has been observed (Froend et al 2000a). A shift in species composition towards the xeric end of the floristic continuum has been observed at a number of long-term monitoring sites (Groom, Froend, Mattiske and Gurner, 2000b). Overstorey species that cannot tolerate long periods of reduced soil water availability are slowly dying-out and being replaced by more drought-tolerant species.

A more acute and noticeable response to reduced soil water availability is events that cause sudden and extensive vegetation deaths. This form of response occurs when rapid groundwater drawdown is combined with low rainfall recharge rates and reducing groundwater tables. An example of this response is summer of 1990/1991 event where up to 80% of all Banksia trees and 60-70% of the understorey died within the vicinity of P50, a production bore in the Pinjar borefield. Although the vegetation is recovering, little is known about the possible changes that have occurred to vegetation characteristics, i.e. whether the recovered vegetation characteristics are significantly different in composition, function and groundwater requirements.

Resilience is a concept that has been presented as a means of defining how an ecosystem copes with change. This concept is important to the way in which complete ecosystems adapt to environmental changes and was introduced to ecology by Holling (1973) as a way to comprehend the non-linear relationships observed in ecosystems. The term resilience has been defined by Holling (1996), as the ability of a plant community to return to a stable state following a perturbation. This definition of resilience examines the changes that occur in a system following a disturbance event, as a way of identifying the degree of plant community resilience. If a community returns to a similar stable state that is representative of what existed before such an event, then the community can be classified as resilient (Gunderson, Holling, Prictchard and Peterson, 2002).

This chapter aims to examine the resilience of Banksia woodland communities to sudden decline episodes. Changes that have occurred in vegetation composition and structure, inferred function and groundwater requirements were examined and contrasted with communities that have not experienced sudden decline events.

5.2 Methods

5.2.1 Site Selection.

The selection process for the site affected by a sudden decline episode has been described in the previous chapter, however, there are a number of other sites that were examined and selected because they fulfilled a set number of selection criteria. A 2003 assessment at P50 and the other long-term monitoring sites was carried out, however, due to sampling differences and bias, they were not compared to Mattiske's data, therefore, a 2003 comparison of non long-term monitoring sites (current status sites) and P50 was completed separately.

Sites that were to be compared to P50 firstly had to have some form of historical data, some with complete vegetation and hydrological data and others with hydrological data only that were close to P50. These sites needed to be close to P50 to be representative of a similar floristic and current state. All of the above sites had to be found within the same vegetation complex. This was done by consulting maps that clearly identified vegetation complexes, demonstrating which bores were located in the various categories.

The first sites needed for a comparison to P50 had to have long-term hydrological and vegetation data. These sites were long-term monitoring sites set up by Mattiske and Associates and have been monitored on a regular basis. The Mattiske sites that were located within the same vegetation complex as P50, also had to have a similar trend to the hydrographic data. This trend indicated a decreasing groundwater level across the Gnangara Mound. Although they cannot be exactly identical, those sites chosen were the best representatives of the trends observed at the P50 production bore.

The second sets of sites needed for comparison were those that had long-term groundwater monitored data and were close to P50. At these sites a 2003 assessment was carried out using the same transect layout as P50 (Figure 5.1 and 5.2) to compare how surrounding vegetation to P50 is different or similar to the vegetation transect at P50 itself. The length of the transects were 60m and included 3, 20m x 40m plots. These sites were referred to as current status sites as they were used to examine the current status of vegetation at P50

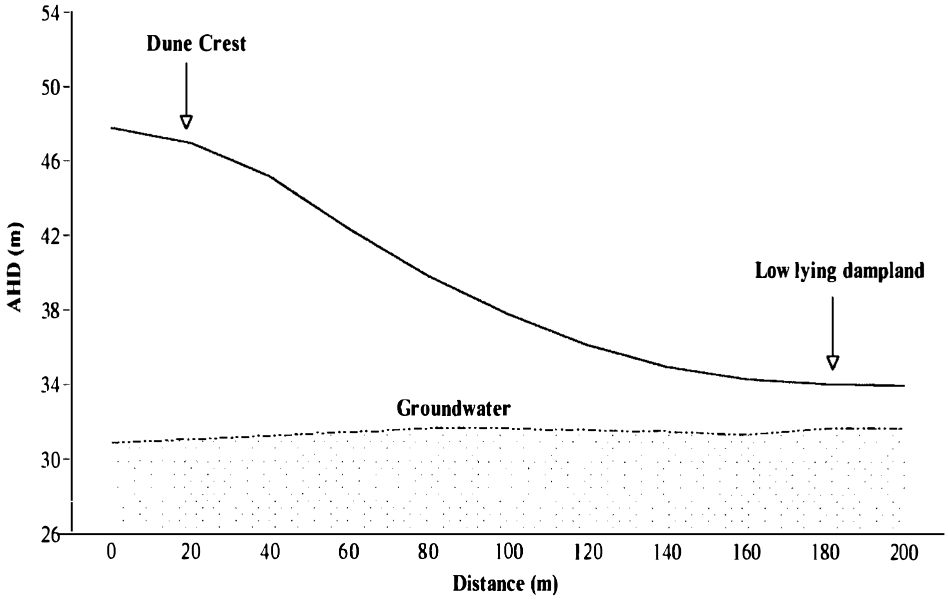


Figure 5.1 Typical topographical and groundwater profile of the vegetation transects (Mattiske and Associates, 1995).

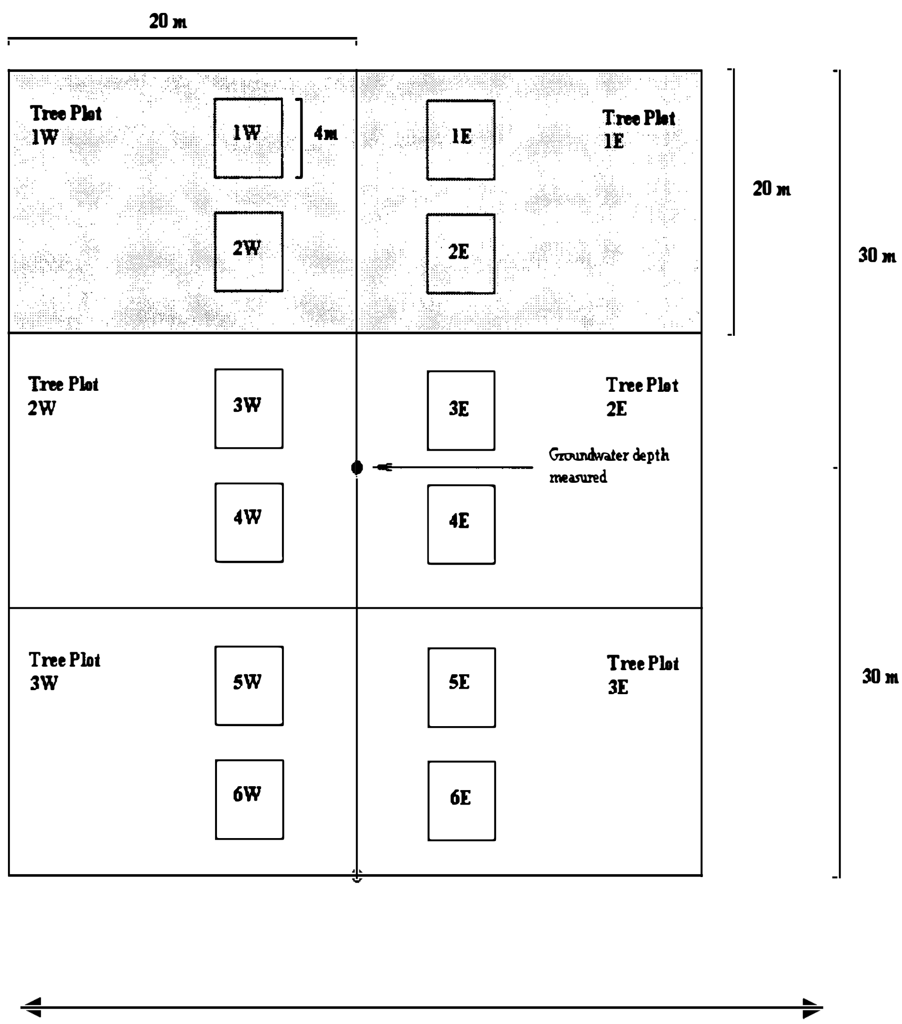


Figure 5.2 Typical layout of vegetation transect. This sequence of plots continues until the end of the transect. The shaded area represents the area used in this study to represent a single sampling unit (Mattiske and Associates, 1995).

5.2.2 Historical Datasets.

Throughout the Gnangara Mound there are 15 transects (located near monitoring bores) that have been set-up as part of a long-term vegetation-monitoring program (Table 5.3). These transects have been monitored every 2 to 4 years since their establishment and date back to 1966, when four transects (Neaves, South Kendall, Tick Flat and West Gironde) were established by Havel (1968), to provide ecological data to determine suitable sites for pine plantation establishment. Havel's four transects were remonitored in 1976 by Mattiske (nee Heddle) whilst working for the Western Australian Forestry Department (Heddle 1980), when it was decided that these four transects would provide useful data on the floristic composition on the Gnangara Mound prior to the commencement of public groundwater abstraction. Three of these transects are within close proximity (< 2 km) to production bores (Neaves, W Gironde, S Kendall, Table 5.1). The Tick Flat transect is >25 km from the nearest production bore. All four transects are monitored as part of the current vegetation monitoring program, except West Gironde which no longer exists as it was partially cleared for urban development in 1987.

In 1976 transects adjacent to Jandabup Lake and Lake Joondalup were established in response to concerns about decreasing lake levels on the fringing native vegetation. Other transects (Nowergup, Ridges, Tangletoe, Yanchep and Yeal Swamp) were created in 1987 to include areas of the Gnangara Mound that were/are currently not under the influence of groundwater abstraction into the monitoring program (Table 5.2). A transect was established within close proximity (~50 m) from the Pinjar bore P50 in 1988. This transect was established prior to the commencement of groundwater abstraction from the bore to directly monitor changes in floristic structure and composition resulting from abstraction.

All transects occur within conservation reserves or on crown land, and were positioned along a topographical gradient starting at a localized depression and ending at a high point in the landscape, usually a dune crest. The transect at P50 was the exception due to its relatively flat landscape. Transects varied from 200 to 520m in length, and were subdivided into two parallel lines down the length of the transect. Each line was further subdivided into 20 x 20m plots for overstorey assessment. Within each of these were two 4 x 4m quadrats used to monitor the understorey (Figure 5.2).

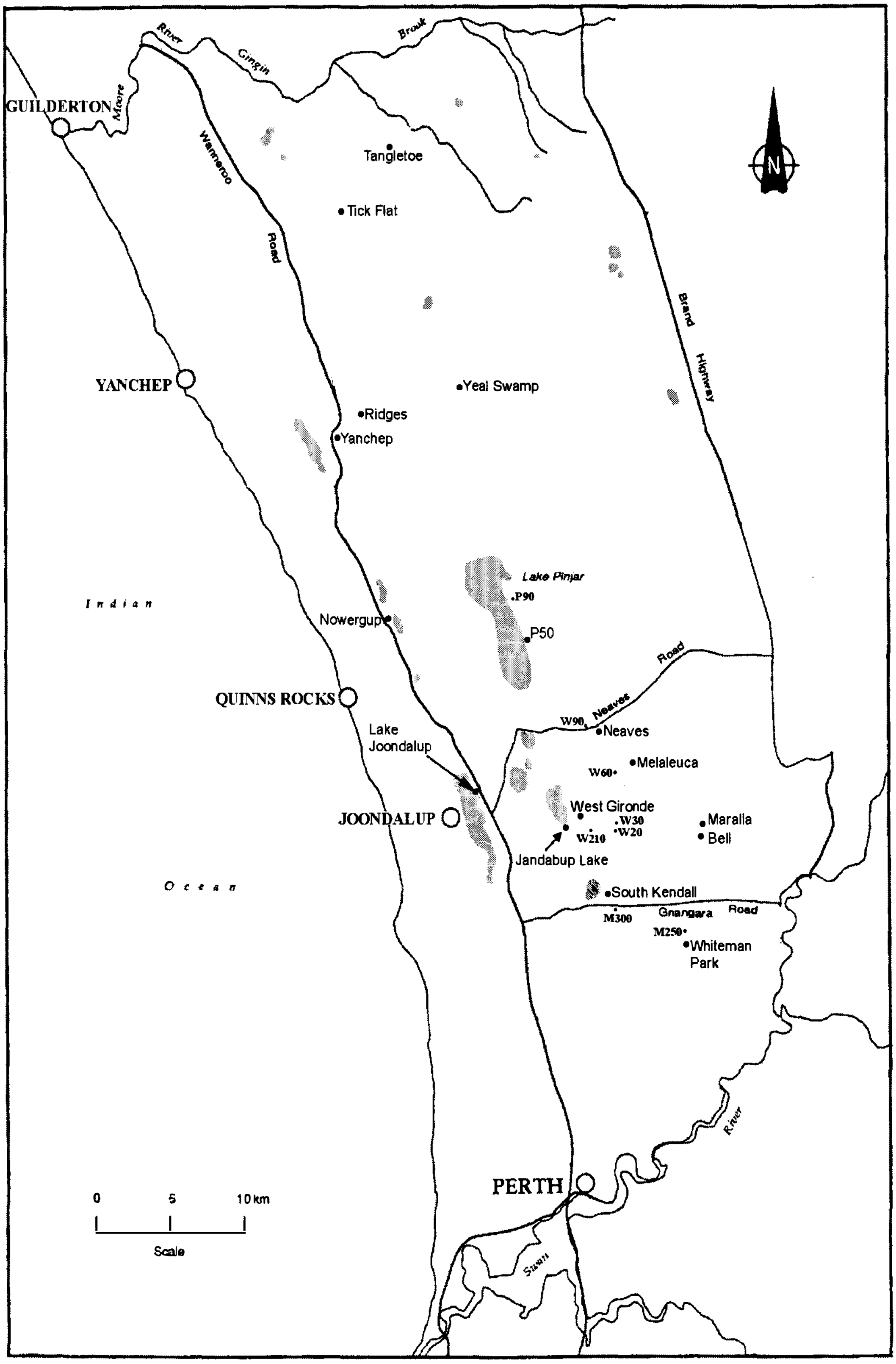


Figure 5.3 Location of monitored vegetation transects (large black dots) and closest groundwater abstraction bores (small black dots) on the Gnangara Mound (Mattiske and Associates, 1995).

Within each overstorey plot, the number of dead and alive plants for each species present was recorded. In addition, the diameter at breast height and the condition of all stems per tree was noted. The condition (vigour) of each stem was categorised as healthy, stressed or dead, primarily based on foliar characteristics. Within each understorey quadrat, the number of plants (alive and dead) for each species present was recorded, and where possible, percentage foliage cover. For species where the numbers of individuals were difficult to count accurately (i.e. grasses and herbaceous species), only their presence was noted. Vegetation assessments occurred in mid to late spring of the designated year (Mattiske, 2000).

Table 5.1 History of transect monitoring on the Gnangara Groundwater Mound. Transects were monitored in Sept-Oct of the designated year (Mattiske and Associates, 1995).

Transect	1966	76	78	80	81	84	87	88	90	91	93	96	99	02
Neaves	●	●	●	●	●	●	●		●		●	●	●	●
Tick Flat	●	●	●	●	●	●	●		●		●	●		●
South Kendall	●	●	●	●	●	●	●		●			●		
West Gironde	●	●	●	●	●	●	●		●					
Jandabup Lake		●	●	●	●	●	●		●		●		●	
Lake Joond		●	●	●	●	●	●		●					
Nowergup							●		●					
Ridges							●		●			●		
Tangletoe							●		●				●	●
Yanchep							●		●		●		●	●
Yeal Swamp							●		●		●	●		●
Gnangara P50								●		●	●	●	●	●
Whiteman Park										●		●	●	●
Bell												●	●	●
Maralla												●	●	
Melaleuca												●	●	●

Table 5.2 Distance of nearest groundwater production and monitoring bores to the centre of the vegetation monitoring transects (Mattiske and Associates, 1995).

Transect	Production bore	Distance (km)	Monitoring Bore	Distance (km)
Within close proximity to production bores (≤ 2 km)				
P50	P50	0.05	P50	0.05
Neaves	W90	1	WM6	0.2
W Gironde	W210	1.2	JB2	0.3
S Kendall	M300	1.3	MM9	0.4
Jandabup Lake	W210	2	JB12A	0.1
Whiteman Park	M250	0.8	MM26	0.8
Melaleuca	W60	1.9	NR12	0.6
Not near production bores (> 2 km)				
Lake Joondalup	W255	6.5	JP20B	0.7
Ridges	P90	12	GA3	1.2
Yanchep	P90	13	YN3	1.5
Yeal Swamp	P90	14.7	Y100	0.3
Tick Flat	P90	27	GA23	2.4
Lake Nowergup	P40	8	LN2/89	0.2
Bell	W20	5.9	PB2	0.3
Maralla	W30	6.5	L130C	0.3
Tangletoe	P90	30	-	-

For the purpose of this study, data from the two longitudinal parallel lines that formed each transect was pooled because of the topographical and groundwater depth gradients exhibited by all transects. Thus, instead of using the data from two adjacent 20 x 20m plots along the same topographic position as separate entities, the data was combined to form one 20 x 40m plot (Figure. 5.2). Therefore each 20 x 40m plot contained overstorey (obtained from combining the two 20 x 20 m plots) and understorey (obtained from combining four 4 x 4m quadrats) data.

Throughout the vegetation monitoring history, groundwater levels along transect have never been quantified. Hydrographs of the closest observation bores to the transects were obtained from Water and Rivers Commission as a means of determining the past hydrological regimes experienced within the region of each transect. Other factors (i.e. fire and rainfall [where rainfall influences groundwater recharge]) that may influence floristic changes on the Gnangara Mound were also investigated.

5.2.3 Vegetation Assessment.

Current vegetation characteristics were assessed for all sites, including P50, in spring/summer of 2003/2004 to examine the current status of the vegetation and ascertain change in measured parameters. The 2003 data will not be compared to Mattiske's data due to sampling biases and differences in techniques, however, the historic data for the sites was compared to ascertain changes in the vegetation. Specifically, analysis of change in species composition (e.g. native vs. exotic), plant biodiversity (species richness), abundance (species site importance, % cover), physiognomy (structural complexity) and function (grouping according to water requirements), was conducted.

To assess current floristics at the chosen sites the methods employed in the historical monitoring were replicated (Figure 5.2). To collect current data the existing transects at the long-term monitoring sites were resampled following the protocols outlined by the available historical data above, and the new sites were designed and monitored identically to the long-term monitored sites, i.e. transects were subdivided into two parallel lines that ran down the length of each transect and each line was further divided into 20m x 20m plots for overstorey assessment, with two 4m x 4m quadrats inside the larger ones used to monitor the understorey (Figure 5.2).

Within each overstorey plot, the number of dead and alive plants for each species present was recorded. The condition of each stem was then categorised as one of the following: healthy, stressed or dead, based on foliar characteristics. For each of the understorey quadrats, the number of plants for each species was recorded, and where possible, the foliar percentage covers for the species. For species where the number of individuals is difficult to count accurately (i.e. grasses and herbaceous species) only their presence was noted.

Changes (or differences) in floristic composition were examined by assessing species composition (e.g. native vs. exotic), plant biodiversity (species richness), abundance (species site importance, % cover), physiognomy (structural complexity) and function (grouping according to inferred water requirements). Water requirements were inferred by analysis of the species' richness and abundance of two biologically important functional groups - life history traits and rooting patterns. Life history traits for each species occurring within the transects will be categorized according to their longevity (annual, perennial), life form (tree, shrub, herb – includes grasses) and whether they were native or exotic. Rooting pattern categories were based on those described by Pate *et al.* (1984) for Western Australian sandplain species. The rooting pattern for each species was determined by consulting published sources (Dodd *et al.* 1984), personal observations and consultation with Prof. John Pate of the Botany Department, University of Western Australia.

5.2.4 Data Analysis.

The analysis of the historical and current datasets was completed in several stages. Initially graphical comparisons at the various sample sites were completed, between and among the sites, to compare total number of species within transects over time, species richness over time and the percentage of exotic species over time. Once this had been completed multivariate analysis techniques (ordination and clustering) were employed to ascertain composition similarity. Abundance data was used when examining changes in composition of overstorey or shrubby understorey species. Percentage frequency data was also used and refers to the number of times that a species occurs across the transect.

Non-metric multidimensional scaling (NMS), an ordination technique, was employed to investigate multi-temporal patterns or floristic 'trajectories'. NMS uses a measure of similarity between sites, replacing the original species composition data by a matrix of similarity values, using this similarity matrix to obtain an ordination diagram. The Euclidean distance between points on the resulting ordination diagram can be used to compare relative changes in species composition between two sites (or monitoring dates). NMS is described in detail in Jongman *et al.* (1995), but in principle attempts to satisfy all the conditions imposed by the ranking of the similarity matrix, in a pre-specified number of dimensions. This is an iterative procedure, attempting to produce the 'best' ordination that represents the similarity matrix data as indicated by a stress value (ranges from 0 to 1). The lower the value (closer to 0) the better the representation. In particular we were interested in relating changes over time between and within the plant communities. The similarity matrix produced for NMS, can also be used as a similarity index (Kent and Coker, 1992).

Bray-Curtis similarity matrixes were completed for presence/absence, abundance and percentage frequency data. Analysis between samples was chosen, and depending on wether the data was presence/absence, or one of the other two, the transformation selected was either presence/absence or square root. An MDS analysis was then completed producing and ordination representative of the dataset entered. 100 restarts were chosen as the number of restarts for the ordinations.

When completing comparisons between transects the data collected in 2003, by Broun, was not added to that collected by Mattiske and Associates to overcome sampling bias and observation errors. This 2003 data was however examined and compared to sites with no long-term monitoring history that were in close proximity to P50 as a means of obtaining current status information on *Banksia* woodlands surrounding P50.

5.3 Results

P50 is the production bore that experienced a drawdown event that lead to a devastating collapse in the *Banksia* woodland surrounding this area. To examine the resilience of *Banksia* woodlands to such an event, the trends and patterns at P50 had to be compared to other areas that were similar in nature. Sites that had historical datasets for both hydrology and vegetation monitoring (Neaves and Yeal Swamp), and those sites that were in close proximity to P50 that had a comprehensive dataset for hydrology only (bores: GNM6, PM and L220A), were used for this comparison.

5.3.1 Floristic attributes of long-term monitored sites (P50, Neaves and Yeal Swamp).

The vegetation found at all of the study sites were generally defined as *Banksia attenuata – Banksia menziesii* woodland (except for the lower lying areas at Neaves and Yeal Swamp, which were characterised as wetland communities dominated mainly by *Melaleucas*), consisting of an open overstorey comprising of these two species of *Banksias* and a relatively complex understorey. Species were spread across a number of families, with a majority of the species being in the following families: *Myrtaceae, Proteaceae, Fabaceae, Cyperaceae, Poaceae, Mimosaceae, Stylidiaceae and Orchidaceae*. Other families were also represented and consisted of species that are commonly found in *Banksia attenuata – Banksia menziesii* woodlands within the Bassendean Sand Dune System.

The floristical data for P50 has been studied in chapter 4, therefore, will not be described in detail. The data described in the previous chapter will be referred to and used in comparison to Neaves and Yeal Swamp.

Neaves Floristics

A total of 110 plant species were found along the transect in 2002 and were spread across a number of families. There were a number of species that were commonly observed along the length of the transect, which included: *Banksia attenuata, Banksia menziesii, Melaleuca priessiana, Hypocalymma augustifolium, Stylidium brunonianum, Xanthorrhoea preissii, Actinotus glomeratus, Comesperma calymega, Conostephium pendulum, Damperia linearis, Leucopogon conostephioides, Stylidium repens,* *Adenanthos cygnorum, Eriostemon spicatus, Hibbertia helianthemoides, Tricoryne elatior, Verticordia nitens, Calytrix flavescens, Hibbertia subvaginata, Lobelia tenuior, Lomandra hermaphrodita, Lomandra sericea, Melaleuca seriata, Petrophile linearis, Drosera paleacea, Gonocarpus pithyoides, Lomandra preissii* and *Regelia ciliata.*

The transect at Neaves is different to P50 in that there was a gradient across its length. The gradient, length of transects and the position of the vegetation communities at Neaves clearly demonstrated the differences between Neaves and P50 (Figure 5.4). There were three community types observed at Neaves and the most dominant vegetation type was representative of the vegetation community at P50. It will be observed later in this chapter that the distinct difference between the floristics at P50 and Neaves is contributed to the other vegetation communities notated (Figure 5.4).

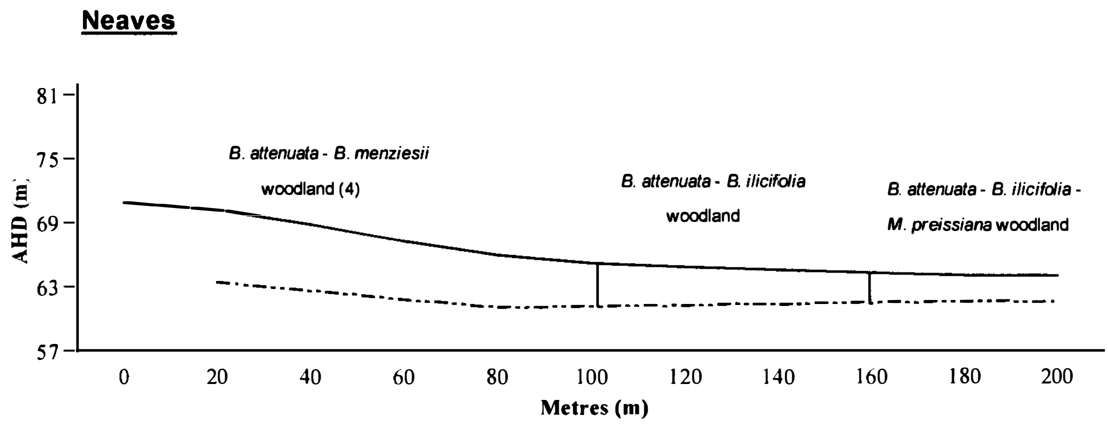


Figure 5.4 Transect at Neaves showing length, ADH (m), and positioning of vegetation communities (Mattiske and Associates, 1995).

The species observed at Neaves, over time, have been classified according to Dodd's (1984) rooting categories and displayed as percentage frequency, as this data was representative of all species observed across the length of the transect (Table 5.3). Percentage frequency refers to the number of times a plant species occurs throughout the transect and provides quantative data for examination. The number of species found at Neaves has remained relatively stable over time, with a slight decrease in the number of species observed in 2002 (Table 5.3).

Rooting pattern codes based on categories listed in Dodd et al. (1984) (Tables 5.3 and 5.4).

1) Shallow fibrous roots (all monocots)
2) Shallow, branched roots
3) Deep sinker roots (insignificant laterals)
4a) Shallow sinker root, significant laterals
4b) Deep sinker roots, significant laterals
5) Horizontal roots
6) Shallow horizontal and vertical roots
7) No roots present (stem parasites)

Table 5.3 %Frequency of Species occurring within the Neaves transect over time.

Rooting depths are classified as shallow (<1m), medium (1<2m) and deep (>2m) and based on the data from Dodd et al. (1984).

	Root	Neaves				
Species	Type	1987	1993	1996	1999	2002
Non-rooting species						
Cassytha glabella	7	10	15	12.5	10	5
Cassytha racemosa	7	0	0	0	0	0
Shallow-rooted species						
Acacia huegelii	4a	0	0	0	0	0
Acacia pulchella	4a	25	30	17.5	15	15
Actinotus glomeratus	2	0	7.5	0	2.5	2.5
Aira caryophyella (1)	1	20	5	0	0	0
Alexgeorgea nitens	1	0	37.5	62.5	55	45
Amphipogan turbinatus	1	2.5	15	22.5	17.5	17.5
Anigozanthos humilis	1	10	7.5	12.5	15	12.5
Anigozanthos manglessii	1	0	2.5	2.5	2.5	0
Arnocrinum preissii	1	0	15	15	2.5	0
Astartea fascicularis	4a	15	12.5	15	15	10
Austrodanthonia occidentalis	1	0	10	0	2.5	0
Austrostipa compressa	1	2.5	0	0	7.5	5
Austrostipa spp	1	5	0	0	0	0
Avena barbata (1)	1	0	0	0	0	2.5
Boronia purdieana	2	20	10	5	2.5	0
Boronia ramosa	2	5	15	15	17.5	17.5
Briza maxima (1)	1	20	60	0	50	60
Burchardia umbellata	1	35	67.5	37.5	65	57.5
Caladenia flava	1	0	5	0	5	10
Caladenia sp.	1	0	5	0	7.5	2.5
Calytrix fraseri	4a	17.5	2.5	0	0	0
Carpobrotus edulis (1)	2	0	0	2.5	0	0
Chamaexeros corymbosa	1	0	10	0	10	7.5
Chordifex microcodon	1	22.5	7.5	7.5	5	5
Comesperma calymega	4a	0	0	12.5	12.5	0
Comesperma virgatum	4a	5	0	0	0	0
Conostylis aculeata	1	27.5	15	17.5	12.5	10
Conostylis juncea	1	22.5	37.5	22.5	22.5	25
Damperia linearis	2	30	25	15	20	15
Dasypogon bromeliifolis	2	50	50	50	50	50
Desmocladus flexuosus	1	32.5	42.5	25	40	27.5
Dielsia stenostachya	1	0	2.5	5	5	2.5
Drosera climbing	1	27.5	60	2.5	47.5	47.5
Drosera erythrorhiza	1	5	42.5	0	20	27.5
Drosera spp	1	2.5	0	0	2.5	5
Ehrharta calycina (1)	1	5	0	0	0	0
Ehrharta longiflora (1)	1	0	0	0	7.5	0
Elythranthera brunonis	1	0	12.5	0	0	7.5
Gladiolus caryophyllaceus (1)	1	2.5	60	70	80	80
Gompholobium confertum	2	5	2.5	0	0	0
Gompholobium tomentosum	4a	15	27.5	22.5	22.5	17.5
Gonocarpus cordiger	2	0	0	0	0	2.5
Gonocarpus pithyoides	2	0	12.5	5	10	2.5
Haemodorum spicatum	1	0	0	0	5	0
Helichrysum spp	2	5	0	0	0	0
Hensmania turbinata	1	0	0	2.5	2.5	0
Hibbertia aurea	4a	2.5	10	2.5	2.5	2.5
Hibbertia helianthemoides	4a	5	7.5	5	7.5	0
Hibbertia racemosa	4a	17.5	17.5	20	22.5	10
Hibbertia subvaginata	4a	50	65	65	60	52.5
Hovea pungens	4a	7.5	5	2.5	5	2.5
Hovea trisperma	4a	5	12.5	15	7.5	5

Hyalosperma cotula	2	42.5	42.5	0	15	50
Hybanthus calycinus	2	2.5	0	0	0	0
Hypocalymma angustifolium	4a	12.5	12.5	15	15	15
Hypocalymma robustum	4a	22.5	20	22.5	22.5	20
Hypolaena exsulca	1	0	2.5	7.5	15	7.5
Hypolaena glabra (1)	2	40	45	37.5	52.5	75
Laxmannia ramosa	1	0	7.5	5	2.5	0
Laxmannia spp	1	7.5	0	0	0	0
Laxmannia squarrosa	1	0	5	2.5	0	2.5
Lepidosperma spp	1	2.5	0	0	0	0
Lepidosperma squamatum	1	12.5	5	2.5	17.5	10
Lomandra brittanii	1	0	0	0	10	5
Lomandra caespitosa	1	2.5	10	12.5	17.5	10
Lomandra drummondii	1	0	0	5	2.5	0
Lomandra hermaphrodita	1	27.5	32.5	60	62.5	47.5
Lomandra preissii	1	0	5	0	7.5	5
Lomandra purpurea	1	0	2.5	0	0	0
Lomandra sericea	1	0	30	30	32.5	15
Lomandra spp	1	2.5	0	2.5	5	2.5
Lyginia barbata	1	57.5	62.5	65	67.5	60
Macrozamia riedlei	4a	5	7.5	7.5	7.5	5
Melaleuca preissiana	4a	25	30	30	30	30
Melaleuca scabra	4a	42.5	42.5	35	37.5	32.5
Melaleuca seriata	4a	20	15	12.5	12.5	5
Microlaena stipoides	1	0	0	2.5	0	0
Microtis media subsp. Media	1	0	12.5	0	2.5	2.5
Nemcia capitata	4a	20	15	7.5	10	7.5
Orchidaceae sp.	1	0	0	0	0	2.5
Patersonia occidentalis	1	62.5	60	62.5	60	50
Patersonia umbrosa	1	5	5	2.5	2.5	0
Pericalymma ellipticum	4a	32.5	30	30	25	17.5
Philotheca spicata	4a	40	42.5	25	22.5	20
Phylebocarya ciliata	1	42.5	40	40	32.5	30
Phyllangium paradoxum	2	0	0	5	30	7.5
Pithocarpa pulchella	2	0	2.5	0	0	0
Podetheca gnaphalioides	2	0	0	0	0	10
Podotheca chrysantha	2	0	17.5	0	35	27.5
Poranthera microphylla	4a	0	0	0	2.5	0
Pterostylis sp	4a	0	0	0	0	5
Regelia ciliata	4a	20	20	20	20	22.5
Regelia inops	4a	10	10	7.5	10	7.5
Schoenus curvifolius	1	22.5	37.5	37.5	22.5	27.5
Siloxerus humifusus	2	0	0	2.5	15	7.5
Sonchus oleraceus (1)	2	0	0	0	5	2.5
Sowerbaea laxiflora	2	0	0	2.5	0	0
Stylidium brunonianum	2	32.5	15	15	20	10
Stylidium calcaratum	2	7.5	12.5	0	12.5	5
Stylidium junceum	2	5	10	0	5	5
Stylidium macrocarpa	2	0	5	10	10	7.5
Stylidium piliferum	2	15	17.5	10	7.5	5
Stylidium repens	2	25	47.5	60	62.5	37.5
Stylidium schoenoides	2	2.5	5	0	5	0
Stylidium spp	2	7.5	0	0	0	0
Thelymitra crinita	1	0	10	0	0	7.5
Thysanothus spp	1	2.5	0	0	0	0
Thysanotus arbuscula	1	5	7.5	17.5	7.5	0
Thysanotus manglesianus	1	17.5	17.5	0	7.5	7.5
Thysanotus multiflorus	1	0	2.5	2.5	2.5	2.5
Thysanotus thyrsoideus	1	0	0	7.5	10	5
Trachymene pilosa	2	0	62.5	5	70	77.5
Tricoryne elatior	1	0	0	0	2.5	0
Ursinia anthemoides (1)	2	62.5	82.5	7.5	77.5	90
Vulpia myuros (1)	1	0	2.5	0	0	10
Xanthorrhoea preissii	1	47.5	45	42.5	42.5	42.5
Xanthosia huegelii	1	2.5	20	10	20	12.5
Medium-rooted species						
Andersonia heterophylla	6	2.5	2.5	2.5	0	0
Astroloma xerophyllum	6	17.5	12.5	7.5	10	12.5
Conostephium minus	6	20	10	7.5	7.5	5
Conostephium pendulum	6	57.5	50	47.5	45	42.5
Conostephium preissii	6	5	2.5	2.5	0	0
Euchilopsis linearis	6	5	7.5	5	7.5	2.5
Heminadra pungens	5	5	7.5	5	2.5	2.5
Hibbertia stellaris	6	5	0	0	0	0
Leptomeria cunninghamii	5	15	0	0	0	0
Leucopogon nutans	6	2.5	0	0	0	0
Leucopogon conostephioides	6	57.5	55	50	52.5	37.5
Leucopogon sprengelioides	6	2.5	0	0	0	0

Lysinema ciliatum	6	2.5	5	5	5	2.5
Oligochaetochilus vittatus	6	0	7.5	0	0	0
Deep-rooted species						
Acacia barbinervis	4b	10	10	5	2.5	0
Adenanthos cygnorum	4b	25	25	27.5	27.5	15
Adenanthos obovatus	4b	27.5	22.5	25	22.5	22.5
Banksia attenuata	4b	90	90	90	90	90
Banksia ilicifolia	4b	45	45	45	45	45
Banksia menziesii	4b	65	70	70	70	70
Beaufortia elegans	4b	45	45	45	45	32.5
Bossiaea eriocarpa	4b	45	52.5	47.5	50	40
Calothamnus lateralis	4b	7.5	2.5	2.5	0	0
Calytrix flavescens	4b	67.5	62.5	65	65	47.5
Eremaea pauciflora	4b	30	27.5	27.5	25	20
Eucalyptus marginata	4b	25	25	25	25	25
Hibbertia huegelii	4b	2.5	5	2.5	2.5	2.5
Jacksonia floribunda	4b	27.5	30	25	25	17.5
Jacksonia furcellata	4b	7.5	50	2.5	2.5	2.5
Kunzea ericifolia	4b	0	2.5	5	10	10
Nuytsia floribunda	4b	35	40	40	40	40
Petrophile linearis	3	72.5	75	67.5	60	42.5
Scholtzia involucrata	4b	22.5	27.5	25	25	25
Stirlingia latifolia	4b	20	22.5	22.5	22.5	17.5

(1) represents exotic species

The largest grouping of species was observed in the shallow-rooted species category, however, it is also clear form this table that there was a general trend in percentage frequency data that indicated a decrease in numbers and frequency of plants across the transect as a whole (Table 5.3). This trend was also observed at P50 and was discussed in the previous chapter.

Yeal Swamp Floristics

At Yeal Swamp a total of 84 plant species were found along the transect in 2002, and were representative of a number of families. Their were a number of species commonly observed throughout the area and these included the following: *Banksia menziesii, Banksia attenuata, Hypocalymma augustifolium, Melaleuca priessiana, Actinotus glomeratus, Stylidium brunonianum, Stylidium repens, Tricoryne elatior, Eriostemon spicatus, Xanthorrhoea preissii, Verticordia nitens, Comesperma calymega, Conostephium pendulum, Damperia linearis, Lobelia tenuior, Leucopogon conostephioides, Adenanthos cygnorum, Hibbertia helianthemoides, Calytrix flavescens, Hibbertia subvaginata, Lomandra hermaphrodita, Regelia ciliata, Melaleuca seriata, Petrophile linearis, Drosera paleacea, Gonocarpus pithyoides, Lomandra preissii* and *Lomandra sericea.*

The transect at Yeal Swamp also differs to P50 in the same way that Neaves does. There is a gradient across the transect from a wetland environment to the *Banksia* woodland found in the upper slopes of the area (Figure 5.5).

Two community types were noted at Yeal Swamp, with the vegetation found on the upper slope representative of the vegetation found at P50 (Figure 5.4). It will be observed later that there are distinct differences between the floristics at P50 and Yeal Swamp, which is contributed to the other vegetation communities observed at the site.

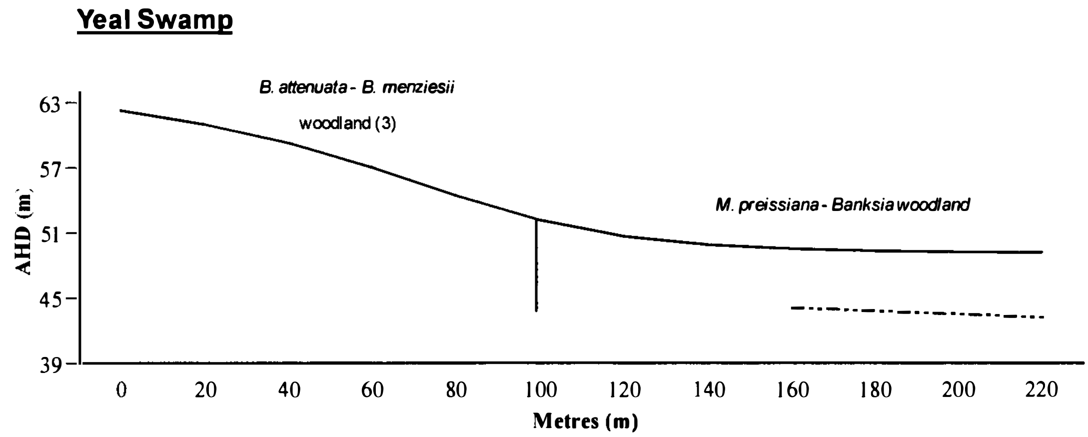


Figure 5.5 Transect at Yeal Swamp showing length, ADH (m), and positioning of vegetation communities (Mattiske and Associates, 1995).

The species at Yeal Swamp have been grouped according to Dodd's (1984) rooting categories and patterns in the same way Neaves was (Table 5.4). The number of species found at Yeal Swamp was also observed to have changed very little over time, however, as with P50 and Neaves the composition of these species varies from year to year.

The largest numbers of species found is in the shallow-rooted species category. However, it is also clear from this table that there was a general trend in percentage frequency data that indicated a decrease in abundance and % frequency across the transect as a whole. This trend was also observed at P50 and Neaves as was discussed earlier in this chapter (Figure 5.4).

Table 5.4 Species % Frequency occurring within the Yeal Swamp transect over time.

Rooting depths are classified as shallow (<1m), medium (1<2m) and deep (>2m) and based on the data from Dodd et al. (1984).

Species	Root Type	1987	1993	1996	2002
		Yeal Swamp			
Shallow-rooted species					
Acacia huegelii	4a	29.5	15.9	11.4	0
Acacia pulchella	4a	40.9	45.5	31.8	38.6
Acacia stenoptera	4a	11.4	11.4	9.1	2.3
Alexgeorgea nitens	1	0	18.2	27.3	2.3
Amphipogan turbinatus	1	4.5	2.3	2.3	0
Anigozanthos humilis	1	2.3	0	0	0
Anigozanthos manglessii	1	2.3	2.3	0	0
Anigozanthos sp.	1	0	4.5	0	0
Aotus procumbens	4a	31.8	20.5	13.6	2.3
Arnocrinum preissii	1	2.3	0	2.3	0
Austrostipa spp	1	4.5	2.3	0	0
Avena fatua (1)	1	0	2.3	0	0
Boronia ramosa	2	43.2	9.1	15.9	36.4
Briza maxima (1)	1	9.1	2.3	0	4.5
Burchardia umbellata	1	0	15.9	0	2.3
Calytrix angulata	4a	9.1	15.9	15.9	15.9
Centaurium erythraea (1)	1	2.3	2.3	2.3	0
Comesperma flavum	4a	2.3	20.5	11.4	9.1
Conostylis aculeata	1	34.1	38.6	40.9	27.3
Conostylis juncea	1	4.5	11.4	4.5	6.8
Corynotheca micrantha	1	6.8	9.1	4.5	0
Damperia linearis	2	2.3	4.5	6.8	4.5
Daucus glochidiatus	1	0	6.8	0	9.1
Desmocladus flexuosus	1	27.3	38.6	40.9	38.6
Drosera paleacea	1	0	0	2.3	0
Drosera spp	1	2.3	0	0	0
Euchiton sphaericus	2	2.3	0	0	0
Gladiolus caryophyllaceus (1)	1	0	2.3	0	0
Gompholobium confertum	2	0	0	0	2.3
Gompholobium tomentosum	4a	65.9	68.2	50	38.6
Haemodorum sp.	1	2.3	0	0	0
Hibbertia hypericoides	4a	36.4	36.4	38.6	34.1
Hibbertia subvaginata	4a	56.8	54.5	54.5	52.3
Hyalosperma cotula	2	4.5	0	0	4.5
Hypocalymma angustifolium	4a	13.6	18.2	20.5	18.2
Hypolaena exsulca	1	0	15.9	11.4	2.3
Hypolaena glabra (1)	2	2.3	9.1	4.5	6.8
Isotropis cuneifolia	2	0	4.5	2.3	2.3
Johnsonia pubescens	1	2.3	2.3	2.3	0
Lagenophora huegelii	1	0	0	0	4.5
Lepidosperma gracile	1	2.3	0	0	0
Lepidosperma sp.	1	0	9.1	0	0
Lepidosperma squamatum	1	9.1	22.7	22.7	4.5
Lepidosperms tenue	1	6.8	0	0	0
Levenhookia pusilla	1	0	0	0	2.3
Levenhookia stipitata	1	0	36.4	0	29.5
Lobelia tenior	2	0	4.5	2.3	20.5
Lomandra caespitosa	1	0	0	4.5	2.3
Lomandra drummondii	1	0	2.3	0	0
Lomandra hermaphrodita	1	34.1	36.4	31.8	9.1
Lomandra sericea	1	2.3	2.3	2.3	2.3
Lomandra spp	1	2.3	0	0	0
Lyginia barbata	1	22.7	31.8	36.4	2.3
Macrozamia riedlei	4a	6.8	6.8	6.8	4.5
Melaleuca preissiana	4a	20	21	21	23
Melaleuca scabra	4a	2.3	2.3	2.3	2.3
Mesomelaena stygia	1	9.1	11.4	11.4	0
Nemcia capitata	4a	34.1	31.8	25	13.6
Patersonia occidentalis	1	13.6	22.7	18.2	6.8
Pericalymma ellipticum	4a	9.1	9.1	9.1	9.1
Philotheca spicata	4a	13.6	20.5	13.6	4.5
Phylebocarya ciliata	1	20.5	29.5	18.2	11.4
Poaceae sp.	1	0	0	0	2.3
Pterochaeta paniculata	2	4.5	4.5	0	9.1
Regelia inops	4a	29.5	34.1	31.8	27.3
Schoenus curvifolius	1	52.3	61.4	52.3	38.6
Siloxerus humifusus	2	0	2.3	0	11.4

Sonchus sp. (1)	2	0	4.5	0	4.5
Stylidium brunonianum	2	29.5	20.5	9.1	31.8
Stylidium calcaratum	2	4.5	0	0	2.3
Stylidium crossocephalum	2	4.5	6.8	2.3	0
Stylidium piliferum	2	0	4.5	2.3	4.5
Stylidium repens	2	29.5	47.7	43.2	38.6
Stylidium schoenoides	2	2.3	2.3	0	0
Stylidium spp	2	2.3	0	0	0
Tetrarrhena laevis	1	0	0	2.27	2.27
Thelymitra crinita	1	0	2.27	0	0
Thysanothus spp	1	2.27	0	0	0
Thysanotus patersonii	1	2.27	0	0	0
Trachymene pilosa	2	0	0	0	2.27
Ursinia anthemoides (1)	2	0	0	0	4.55
Vulpia myuros (1)	1	0	0	2.27	2.27
Xanthorrhoea gracilisi	1	2.27	0	0	0
Xanthorrhoea preissii	1	40.91	40.91	40.91	40.91
Xanthosia huegelii	1	25	18.18	4.55	6.82
Medium-rooted species					
Andersonia lehmanniana	6	15.9	13.6	4.5	0
Conostephium pendulum	6	34.1	36.4	36.4	27.3
Croninia kingiana	6	2.3	2.3	2.3	0
Heminadra pungens	5	50	36.4	31.8	29.5
Kennedia prostrata	6	2.3	2.3	0	2.3
Leucopogon polymorphus	6	29.5	29.5	22.7	13.6
Leucopogon propinquus	6	2.3	2.3	2.3	2.3
Leucopogon conostephioides	6	54.5	52.3	54.5	22.7
Leucopogon sp.	6	2.3	0	0	0
Deep-rooted species					
Acacia saligna	4b	0	0	2.3	2.3
Adenanthos cygnorum	4b	52.3	50	50	34.1
Allocasuarina humilis	4b	2.3	2.3	2.3	0
Banksia attenuata	4b	54	55	58	59
Banksia ilicifolia	4b	23	21	22	23
Banksia menziesii	4b	60	64	62	64
Bossiaea eriocarpa	4b	45.5	47.7	45.5	27.3
Calothamnus sanguineus	4b	29.5	29.5	29.5	27.3
Calytrix flavescens	4b	31.8	31.8	31.8	25
Eremaea asterocarpa	4b	6.8	6.8	4.5	4.5
Eucalyptus rudis	4b	25	26	26	27
Eucalyptus todtiana	4b	45	48	49	50
Hibbertia huegelii	4b	31.8	25	29.5	29.5
Jacksonia furcellata	4b	36.4	31.8	34.1	18.2
Jacksonia sternbergiana	4b	20.5	11.4	9.1	4.5
Kunzea ericifolia	4b	77.3	81.8	81.8	84.1
Nuytsia floribunda	4b	22	23	25	27
Persoonia comata	4b	11.4	6.8	9.1	6.8
Petrophile linearis	3	29.5	31.8	31.8	31.8
Petrophile macrostachya	3	6.8	6.8	6.8	6.8
Scaevola canescens	3	0	2.3	0	0
Scholtzia involucrata	4b	40.9	43.2	36.4	36.4
Stirlingia latifolia	4b	13.6	13.6	11.4	11.4
Synaphea spinulosa	4b	15.91	11.36	13.64	4.55
Verticordia nitens	4b	22.73	20.45	18.18	18.18

(1) represents exotic species

5.3.2 Life history, rooting patterns and tree data for long-term monitored sites.

Total plant abundance at P50, Neaves and Yeal Swamp, was observed to be decreasing over time, regardless of whether the site had experienced a sudden decline event or not (Figure 5.6). The missing data in Yeal Swamp's dataset was due to a lack of monitoring in 1999.

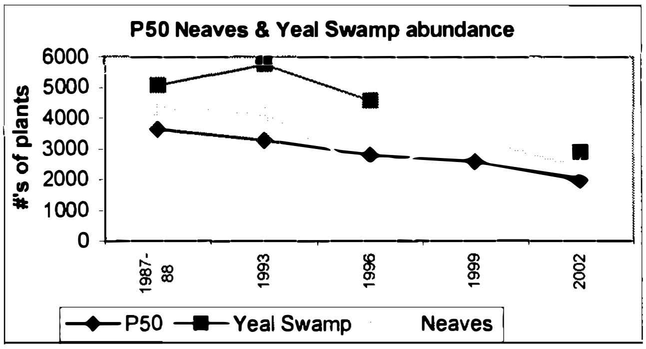


Figure 5.6 Total plant abundance over time at the long-term monitored sites P50, Neaves and Yeal Swamp.

Comparisons of the life history traits revealed that there had been a slight increase in annuals and herbs across the transects over time (Figures 5.8 and 5.9 respectively). This increase is also evident, although less so, where the number of exotic species increased slightly between 1988 and 2002 (Figure 5.7). Although this increase is evident, the total numbers of species found across the transects has not changed significantly between 1988 and 2002. The total number of species at Neaves and Yeal Swamp, however, are higher than those at P50, and is attributed to the increased number of vegetation types observed at Neaves and Yeal Swamp (Figures 5.4 and 5.5). The trends observed were consistent across all of the transects long-term monitored sites.

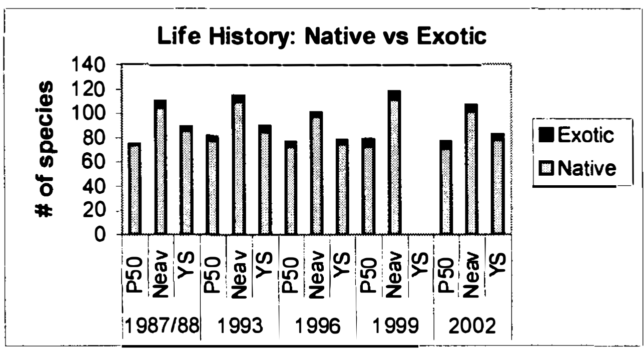


Figure 5.7 Species richness over time. Highlighting - Life History: Total numbers of exotic and native species over time at P50, Neaves and Yeal Swamp.

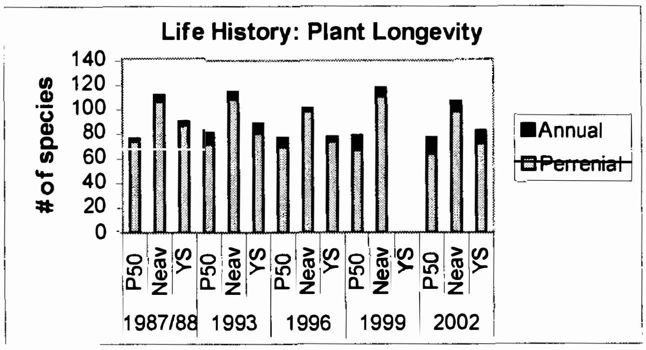


Figure 5.8 Life History: Plant Longevity – Total number of annual and perennial species found at P50, Neaves and Yeal Swamp over time.

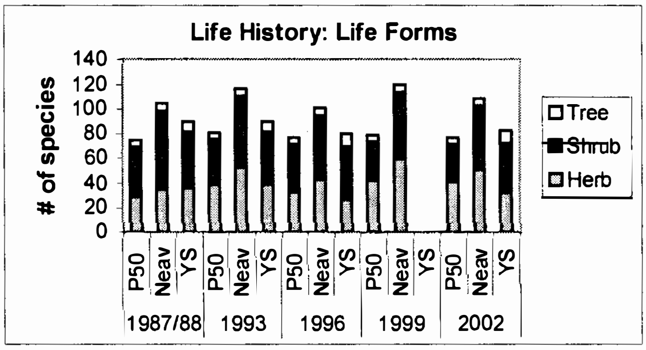
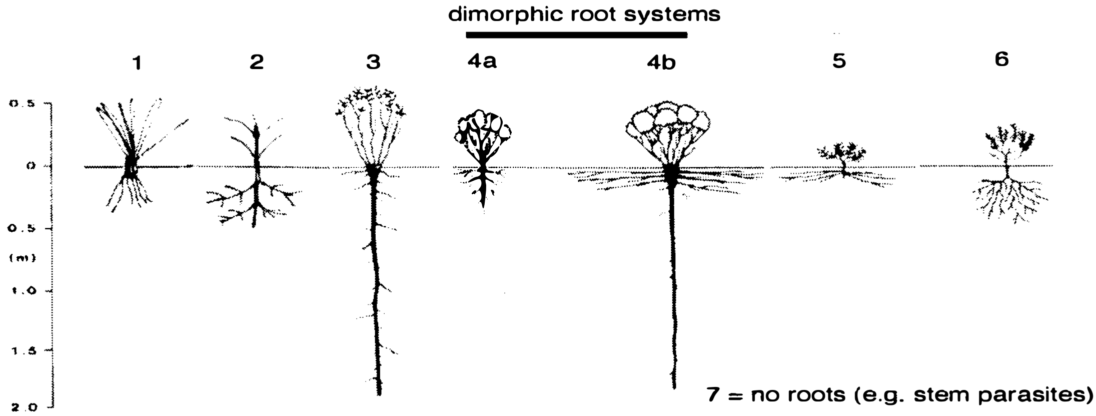


Figure 5.9 Life History: Life Forms – Numbers of species found in varying life forms (Trees, Shrubs and Herbs (which includes grasses) over time at P50, Neaves and Yeal Swamp.

In addition to studying the life history traits as a way of examining the floristical patterns at these sites, the rooting patterns were also categorized and graphed. The rooting patterns were classified according to Dodd et al. (1984) and compared the total number of species and total number of plants at each of the sites.

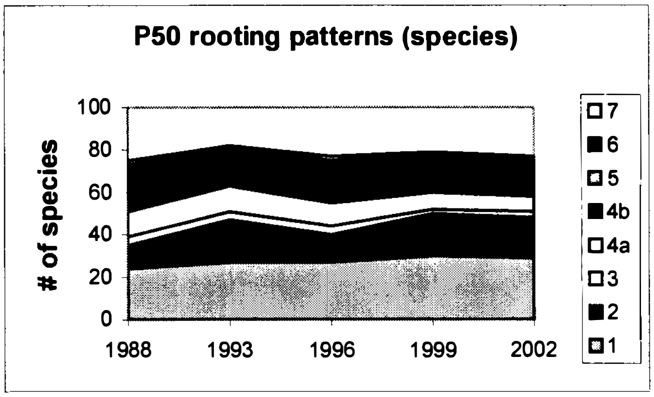


Rooting pattern notes (extracts from Pate *et al.* 1984)	
Types 1 and 2	These rooting patterns mainly occur in monocotyledonous families, where the root system of adult plants is largely, if not entirely, of adventitious origin, as well as in predominately herbaceous plant of other families.
Type 3	Tap-rooted plants are most common in the Fabaceae and Goodeniaceae.
Type 4	The vertical and horizontal root morphology type occurs predominately in woody genera. It is especially well displayed in the families Myrtaceae, Proteaceae, Fabaceae and Epacridaceae.
Type 5	Root systems with only shallow horizontal main roots are only occasionally expressed by the larger families, though universal among species of root hemi-parasites. This type of root is very rare among herbaceous species, and, in woody species, is often associated with a capacity to develop root suckers.
Type 6	This type involves stout woody roots with branches neither predominately vertical nor horizontal, and is highly infrequent, though present.
Type 7	Stem parasites.

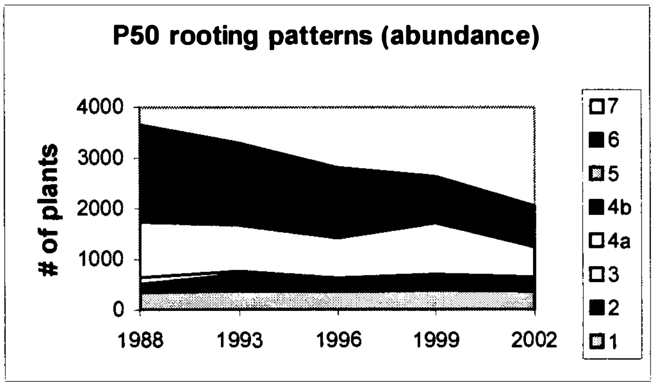
Figure 5.10 Rooting patterns of the Swan Coastal Plain. Modified from Dodd *et al.* (1984) and Pate *et al.* (1984). Rooting pattern numbers as used by Pate *et al.* (1984), with Type 4 (dimorphic rooting pattern) divided into shallow and deep-rooted species. This figure is the interpretation key for the following figures.

There are three observable changes within the rooting types at these three sites (Figures 5.11a, c and e). The first was the increase in shallow fibrous rooted plant species for P50 and Neaves, and a decrease in these species at Yeal Swamp. This number of plant species for P50 and Neaves increased over time at a rate of about 1 species every three years. The second noted change was the increase of shallow branched rooted plant species at all three sites. The increase in these plant species is slightly greater at P50 than the other two. The third noticeable change was in the rooting type 4a, which were those species with shallow sinker roots with significant laterals. The number of species in this category decreased over time at P50, but not noticeably at the other two sites.

a)



b)



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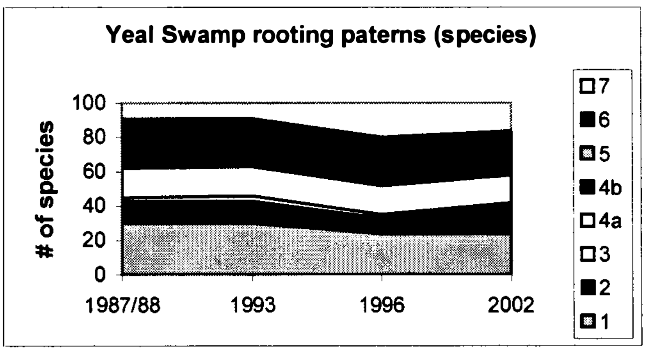
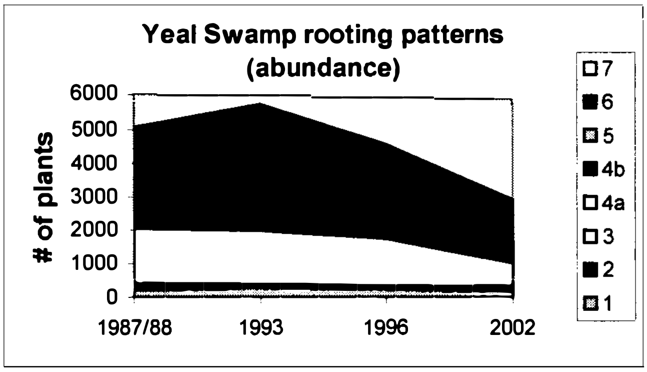
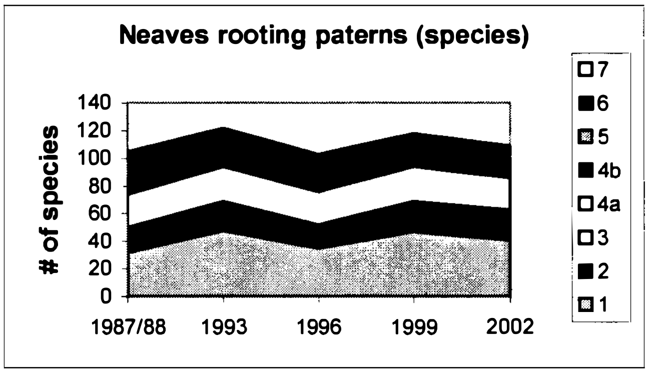


Figure 5.11 **a)** P50 Rooting Patterns over time. Data: total number of species found within each rooting type over time.
b) P50 Rooting Patterns over time. Data: total numbers of plants found within each rooting type over time.
c) Yeal Swamp Rooting Patterns over time. Data: total number of species found within each rooting type over time.
d) Yeal Swamp Rooting Patterns over time. Data: total numbers of plants found within each rooting type over time.
e) Neaves Rooting Patterns over time. Data: total number of species found within each rooting type over time.
f) Neaves Rooting Patterns over time. Data: total numbers of plants found within each rooting type over time.

d)



e)



f)

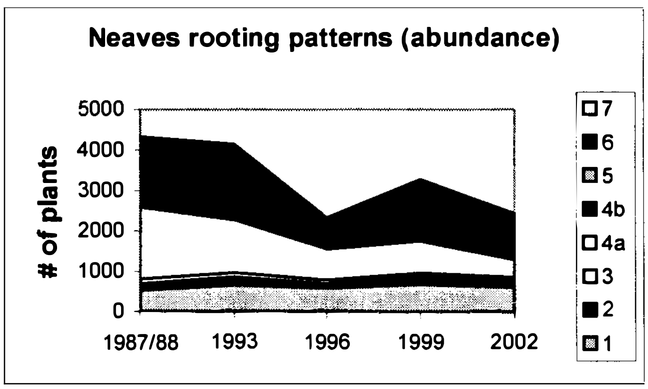


Figure 5.11 **a)** P50 Rooting Patterns over time. Data: total number of species found within each rooting type over time.
b) P50 Rooting Patterns over time. Data: total numbers of plants found within each rooting type over time.
c) Yeal Swamp Rooting Patterns over time. Data: total number of species found within each rooting type over time.
d) Yeal Swamp Rooting Patterns over time. Data: total numbers of plants found within each rooting type over time.
e) Neaves Rooting Patterns over time. Data: total number of species found within each rooting type over time.
f) Neaves Rooting Patterns over time. Data: total numbers of plants found within each rooting type over time.

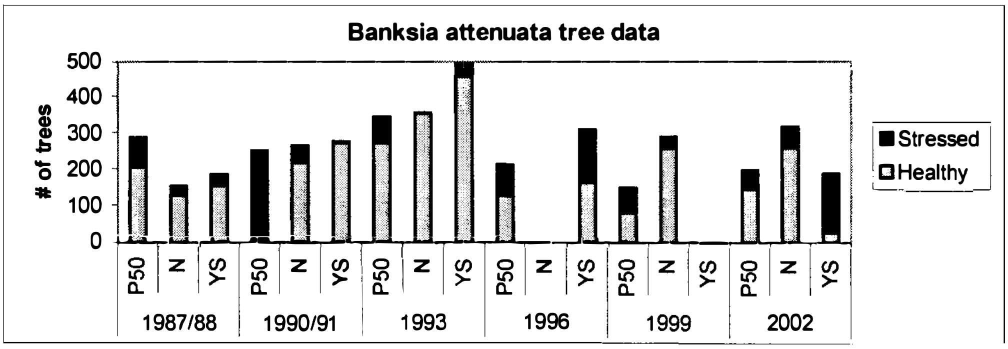
There was an observable decreasing lineal relationship in the total plant abundances across all rooting types (Figures 5.11b, d and f). The most obvious change was in two of the deeper-rooted categories 4a and 4b. These two categories represented those species with shallow sinker roots, with significant laterals and those that have deep sinker roots, with significant laterals. This change was expected at P50 because, with a sudden change in groundwater, the deeper groundwater dependent species had no time to adapt to rapid groundwater changes, therefore, those species that were not drought tolerant died or become severely stressed, due to lack of water. However, at the other two long-term monitored sites, the change in groundwater was gradual so this observation was not necessarily expected, as the plants did have time to adapt. .

The three main tree species found at the three long-term monitored sites were *Banksia attenuata, Banksia illicifolia* and *Banksia menziesii. Banksia ilicifolia* is usually found in the middle to lower slopes and depressions where depth to groundwater is relatively low. The other two species, *Banksia attenuata* and *Banksia menziesii* can tolerate a greater range in conditions, therefore, have a greater ability to adapt to a changing hydrological regime if time permits them to (Allen, 1981).

Changes in the vigour of all three *Banksia* species at P50 have been significant (Figure 5.12). The most observable and dramatic change occurred in 1991 where a 70 percent, 60 percent and 90 percent decline in healthy individuals of *Banksia ilicifolia, Banksia attenuata* and *Banksia menziesii* occurred. It was just prior to this monitoring data that groundwater abstraction had occurred and reduced winter rainfall had led to low recharge and the combination of the two, along with increased pressures by external groundwater users, caused the sudden change in vigour across the transect.

Since the decline in vigour that had been detected in 1991, *Banksia ilicifolia* has experienced minimal re-establishment across the transect and the few that remain are very stressed individuals with poor vigour and growth. However, both *Banksia attenuata* and *Banksia menziesii* have shown an increase in vigour and establishment at all dates following 1991. *Banksia attenuata* has recovered better than *Banksia menziesii* over this time period, however, *Banksia attenuata* was, and is, the dominant overstorey species (Figure 5.12).

a)



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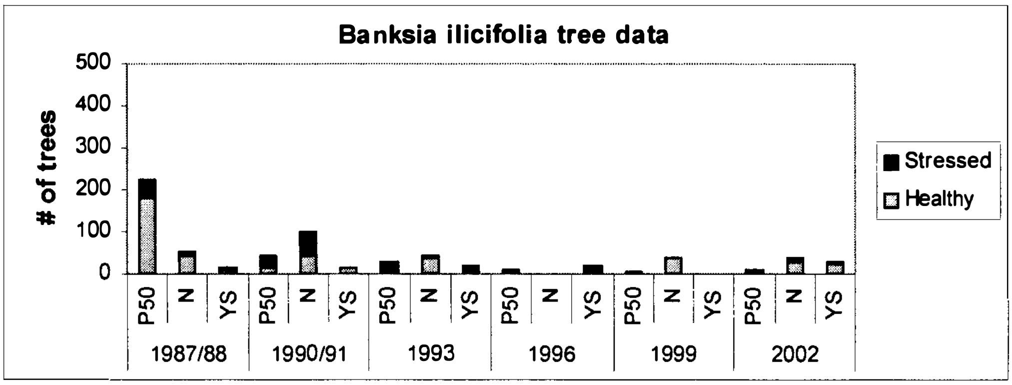

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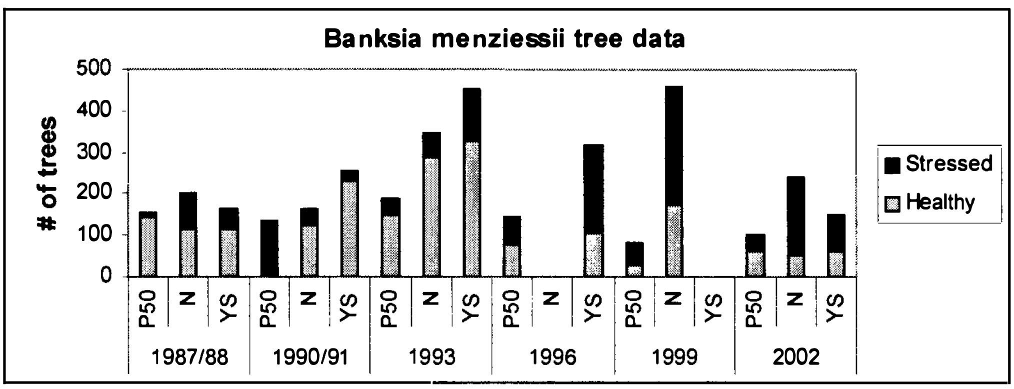


Figure 5.12 **a)** Changes in abundance adult vigour for *Banksia attenuata* at P50, Neaves and Yeal Swamp 1987/88 - 2002.
b) Changes in abundance adult vigour for *Banksia ilicifolia* at P50, Neaves and Yeal Swamp 1987/88 - 2002.
c) Changes in abundance adult vigour for *Banksia menziesii* at P50, Neaves and Yeal Swamp 1987/88 - 2002.

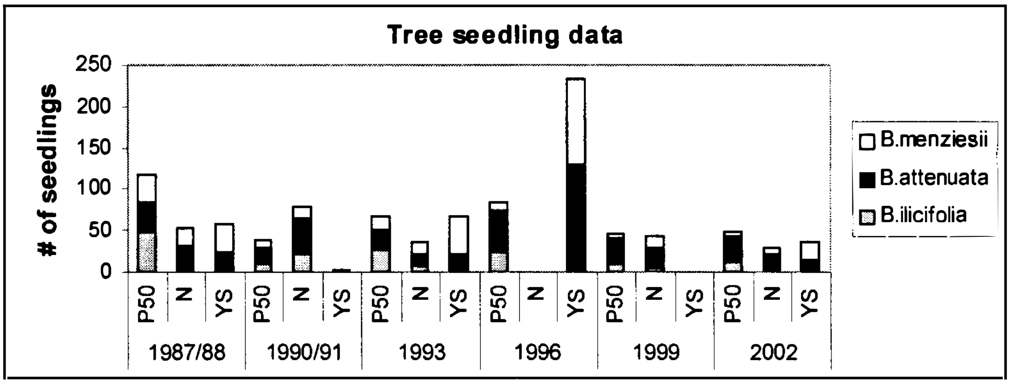


Figure 5.13 Changes in seedling abundance for *Banksia ilicifolia, Banksia attenuata* and *Banksia menziesii* at P50, Neaves and Yeal Swamp 1987/88 – 2002.

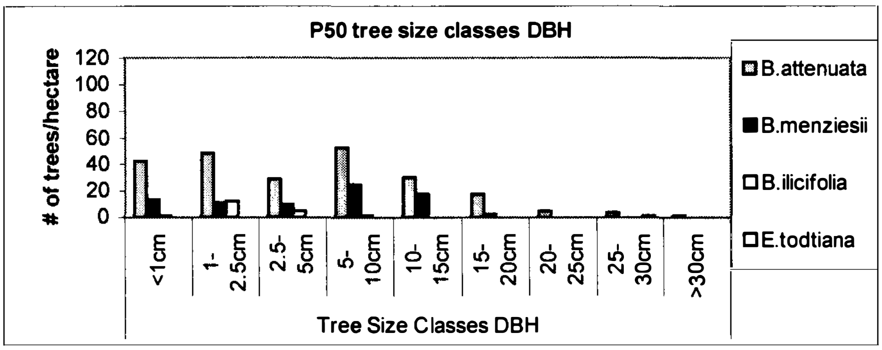
The change in the vigour of the three main Banksia species has been less significant at Neaves than P50 (Figure 5.12). The most observable and dramatic change occurred in the Banksia menziesii vigour, which was detected in 1999 with a drop in vigour by 60 percent. The vigour of the other two species has not fluctuated significantly, however, the number of *Banksia attenuata* has increased over time along this transect and has remained relatively healthy.

The proportion of seedlings present at Neaves has remained relatively even, however, the numbers of *Banksia illicifolia* has decreased and no seedlings were recorded in the last count. This would be expected as the number of *Banksia illicifolia* adults is low and with declining watertable levels their recruitment would be expected to decrease (Figure 5.13).

At Yeal Swamp the change in vigour had also been less significant than the change seen at P50. The most observable and dramatic change occurred in the *Banksia attenuate* and *Banksia menziesii* vigour, where in 1996 the number of trees increased by about 40 percent, and then by the next monitored date, both the number of plants and the vigour had radically reduced and has not recovered (Figure 5.12). The vigour of *Banksia illicifolia* remained fairly consistent throughout the monitored period and has not fluctuated significantly. The proportion of seedlings present has fluctuated greatly, with a huge increase in numbers in 1996 (Figure 5.13).

The size class description for the long-term monitored sites demonstrated that in 2003 Neaves and Yeal Swamp had the same characteristics as P50. The age classes of the trees at these three sites were similar and had responded to reduced water availability in a similar way over time. They appeared to be in a similar state in regards to age distribution in their current state (Figure 5.14). A trend displaying a low percentage of trees in the larger size classes was observed, with the dominant size classes being 5-10cm and 10-15cm.

a)



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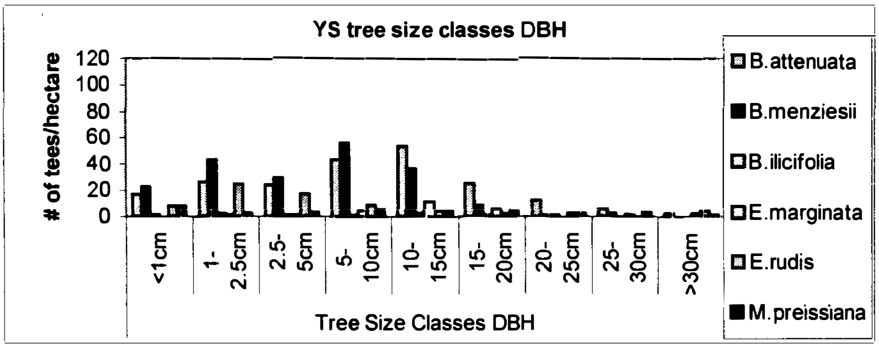

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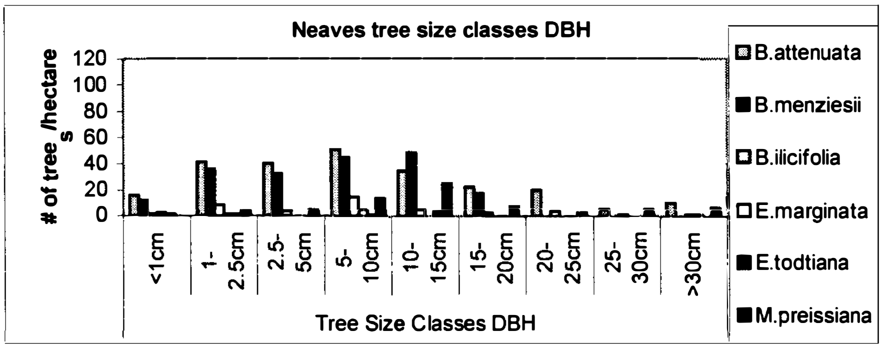


Figure 5.14 **a)** P50 size class distribution in 2003. Measured DBH.
b) Yeal Swamp size class distribution in 2003. Measured DBH.
c) Neaves size class distribution in 2003. Measured DBH.

5.3.3 Indicator species (Havel, 1968) for P50, Neaves and Yeal Swamp.

Havel (1968), in one of his papers described and identified a number of plants as indicator species for the status of a plant community along a spectrum of tolerance to water availability. Havel's indicator species represented at P50, Neaves and Yeal Swamp, have been identified and described (Tables 5.5, 5.6 and 5.7). The data is represented in percentage frequency, as it is the most comprehensive quantative data set.

At P50 the greatest number of species defined by Havel falls into the category of species with max development on dry sites. This observation shows that the largest group of plant species are located at the xeric end of the scale. The category with the second highest number of indicator species is those species that do not have clear-cut site preference (Table 5.5).

Havel's indicator species demonstrated that the vegetation transect Neaves was also dominated by species with maximum development on dry sites. The other classifications for understorey species were relatively evenly distributed in regards to the numbers of Havel's indicator species that were present (Table 5.6).

At Yeal Swamp there was no clearly dominant category, however, there was a large portion of species found in the categories, species with maximum development on dry sites and species with no clear-cut site preference (Table 5.7).

The most important observation to be noted from Havel's indicator species was that a significant proportion of the species represented in each category were the same and that the greatest portion of species was at the xeric end of the continuum. This was an important observation because, as these sites dry out, it will be those species that can tolerate dryer conditions that will survive.

Table 5.5 Havel's Species Categories (1968)
Categorising species in relation to site preference.
Indicator Species highlighted in table.
Data in % Frequency.

Species	Root Type	1988	1993	P50 1996	1999	2002
Tree Species						
Species of optimum moist sites						
Banksia ilicifolia	4b	100	100	100	100	100
Species with a wide tolerance, but with max development on dry sites						
Banksia attenuata	4b	100	100	100	100	100
Banksia menziesii	4b	100	100	100	100	100
Species without clear cur site preference						
Eucalyptus todtiana	4b	0	0	0	0	5
Nuytsia floribunda	4b	5	10	7.5	7.5	15
Understorey Species						
Species tolerant of excessive wetness						
Euchilopsis linearis	6	32.5	20	10	2.5	5
Species of optimum moist sites						
Dasypogon bromeliifolius	2	100	100	100	97.5	97.5
Phlebocarya ciliata	1	70	65	57.5	57.5	57.5
Xanthorrhoea preissii	1	75	75	77.5	77.5	75
Species with max development on dry sites						
Beaufortia elegens	4b	0	0	2.5	5	7.5
Leucopogon conostephioides	6	85	72.5	62.5	57.5	60
Scholtzia involucrate	4b	17.5	15	12.5	12.5	10
Eremaea pauciflora	4b	2.5	2.5	2.5	2.5	2.5
Jacksonia floribunda	3	22.5	12.5	7.5	7.5	7.5
Species without clear-cut site preference						
Conostephium pendulum	6	55	52.5	50	47.5	47.5
Bossiaea eriocarpa	4b	7.5	7.5	5	5	5
Calytrix flavescens	4b	52.5	55	55	45	42.5

Table 5.6 Havel's Species Categories (1968)
Categorising species in relation to site preference.
Indicator Species highlighted in table.
Data in % Frequency.

Species	Root Type	1987	1993	Neaves 1996	1999	2002
Tree Species						
Species of excessive wetness						
Melaleuca preissana	4a	25	30	30	30	30
Species of optimum moist sites						
Banksia ilicifolia	4b	45	45	45	45	45
Eucalyptus marginata	4b	25	25	25	25	25
Species with a wide tolerance, but with max development on dry sites						
Banksia attenuata	4b	90	90	90	90	90
Banksia menziesii	4b	65	70	70	70	70
Species without clear cur site preference						
Nuytsia floribunda	4b	35	40	40	40	40
Understorey Species						
Species tolerant of excessive wetness						
Calothamnus lateralis	4b	7.5	2.5	2.5	0	0
Euchilopsis linearis	6	5	7.5	5	7.5	2.5
Hibbertia stellaris	6	5	0	0	0	0
Hypocalymma angustifolium	4a	12.5	12.5	15	15	15
Regelia ciliata	4a	20	20	20	20	22.5
Species of optimum moist sites						
Adenanthos obovata	4b	27.5	22.5	25	22.5	22.5
Dasypogon bromeliifolius	2	50	50	50	50	50
Melaleuca seriata	4a	20	15	12.5	12.5	5
Phlebocarya ciliata	1	42.5	40	40	32.5	30
Xanthorrhoea preissii	1	47.5	45	42.5	42.5	42.5
Species with max development on dry sites						
Austroloma xerophyllum	6	17.5	12.5	7.5	10	12.5
Beaufortia elegens	4b	45	45	45	45	32.5
Boronia purdieana	2	20	10	5	2.5	0
Conostephium minus	6	20	10	7.5	7.5	5
Eremaea pauciflora	4b	30	27.5	27.5	25	20
Hibbertia helianthemoides	4a	5	7.5	5	7.5	0
Jacksonia floribunda	4b	27.5	30	25	25	17.5
Leucopogon conostephioides	6	57.5	55	50	52.5	37.5
Melaleuca scabra	4a	42.5	42.5	35	37.5	32.5
Scholtzia involucrata	4b	22.5	27.5	25	25	25
Species without clear-cut site preference						
Bossiaea eriocarpa	4b	45	52.5	47.5	50	40
Calytrix flavescens	4b	67.5	62.5	65	65	47.5
Conostephium pendulum	6	57.5	50	47.5	45	42.5
Hibbertia subvaginata	4a	50	65	65	60	52.5

Table 5.7 **Havel's Species Categories (1968)**
Categorising species in relation to site preference.
Indicator Species highlighted in table.
Data in % Frequency.

Species	Root Type	Yeal Swamp 1987	1993	1996	2002
Tree Species					
Species of excessive wetness					
Melaleuca preissana	4a	20	21	21	23
Species of optimum moist sites					
Banksia ilicifolia	4b	23	21	22	23
Species with a wide tolerance, but with max development on dry sites					
Banksia attenuata	4b	54	55	58	59
Banksia menziesii	4b	60	64	62	64
Species without clear cur site preference					
Eucalyptus todriana	4b	45	48	49	50
Nuytsia floribunda	4b	22	23	25	27
Understorey Species					
Species tolerant of excessive wetness					
Hypocalymma angustifolium	4a	13.6	18.2	20.5	18.2
Species of optimum moist sites					
Phlebocarya ciliata	1	20.5	29.5	18.2	11.4
Xanthorrhoea preissii	1	40.91	40.91	40.91	40.91
Species with max development on dry sites					
Leucopogon conostephioides	6	54.5	52.3	54.5	22.7
Melaleuca scabra	4a	2.3	2.3	2.3	2.3
Scholtzia involucrata	4b	40.9	43.2	36.4	36.4
Species without clear-cut site preference					
Bossiaea eriocarpa	4b	45.5	47.7	45.5	27.3
Calytrix flavescens	4b	31.8	31.8	31.8	25
Hibbertia subvaginata	4a	56.8	54.5	54.5	52.3

5.3.4 Data Analysis for long term-monitored sites.

To evaluate the changes that have occurred over time at P50, Neaves and Yeal Swamp, a number of ordination techniques were employed to investigate multi-temporal patterns or floristic 'trajectories'

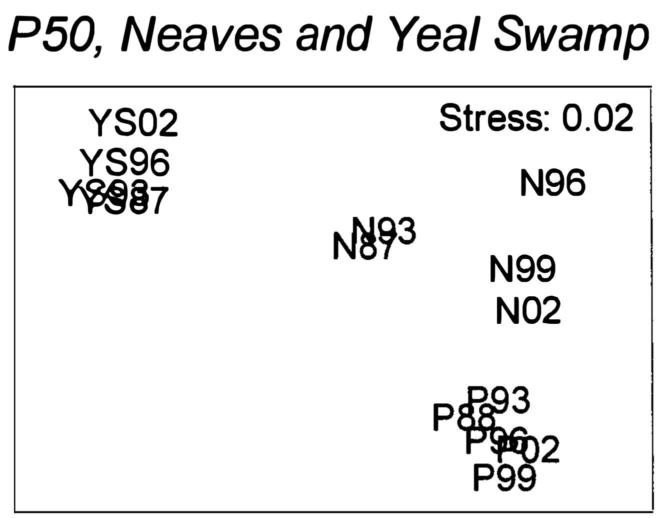


Figure 5.15 Bray-Curtis Similarity Matrix at P50, Neaves and Yeal Swamp over time (MDS). Data is representative of Percentage frequency data.

The difference between P50, Neaves and Yeal Swamp floristically, was observed to be greater than the difference within the sites themselves (Figure 5.15). This can be seen through the clumping of each of the sites on the ordination (Figure 5.15). It is for this reason that we examined the transects individually to obtain a feel for the trends within the transects, without any biases from the other sites interfering with each transects specific trends.

P50 experienced a one-way directional change from its original state at all levels of examination, and this is observable through the percentage frequency data (Figure 5.16). This trend was expected as P50 had experienced a sudden decline event and change was expected at this site. The other two sites, however, also portray this one-way direction trend. The transects have changed at a similar rate over time, and they are all substantially different from their original recorded state. It can also be notated that the stress factor for these ordination matrixes is zero, which means that the data is represented in the best possible way by the ordination.

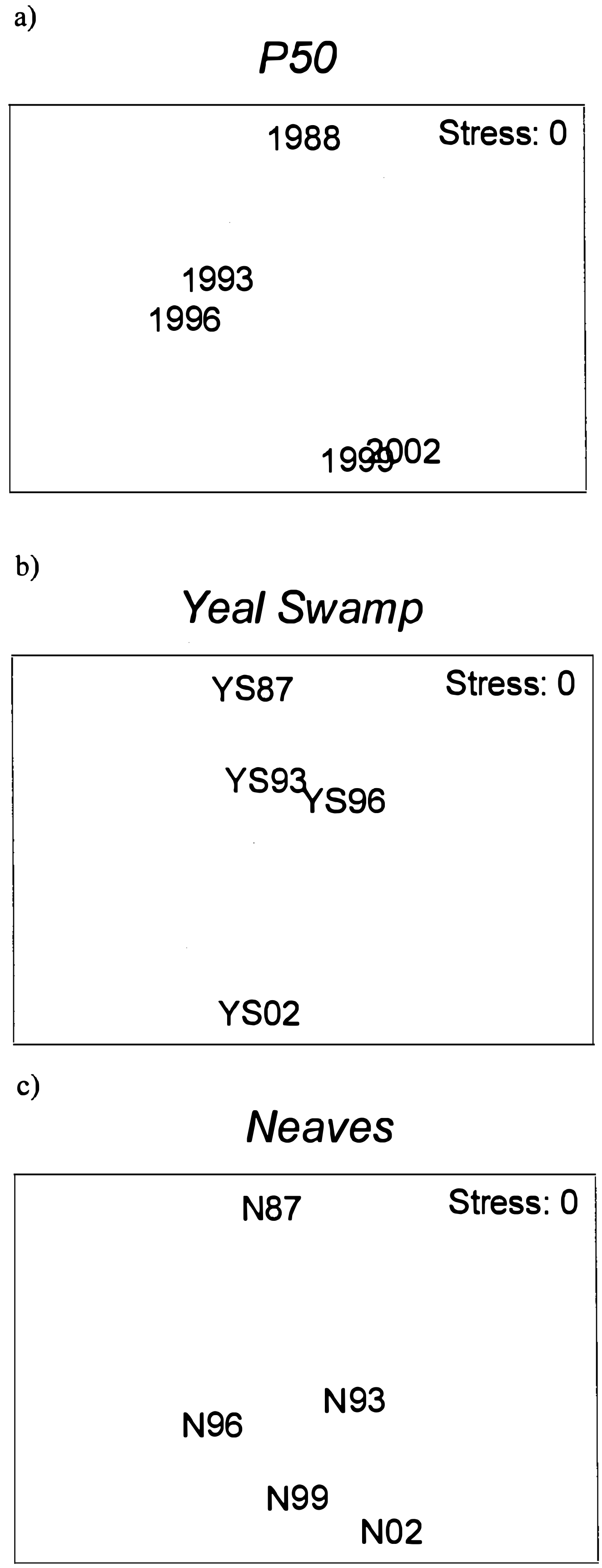


Figure 5.16 Bray-Curtis Similarity Matrix at P50, Neaves and Yeal Swamp over time (MDS). Data based on percentage frequency data.

The same trends were observed for the ordinations completed on species presence/absence data and on abundance data, however, the percentage composition datasets was the most comprehensive and, therefore, included.

5.3.5 Hydrological pattern for current status study sites (L220A, PM9 and GMN6).

There were three current status sites that have long-term monitored hydrological patterns and no vegetation data, except for that taken in 2003 as part of this study. These transects were located next to the monitoring bores L220A, PM9 and GNM6, and were located in the same vegetation complex as P50 and were in close proximity to the P50 production bore. The reason for this is so that the 2003 assessment at P50 could be compared to other sites with very similar vegetation characteristics, close to where the drawdown event occurred, and with sites that did not experience a sudden decline event themselves.

The hydrographs for the bores L220A, PM9 and GMN6 demonstrated the seasonal fluctuation in the watertable and displayed an even pattern across the time scale. The hydrographs also demonstrated a gradual lowering of the watertable seen throughout the Gnangara Mound, however, this was less obvious in the hydrograph for bore L220A, although the trend was still evident (Figure 5.17).

a)

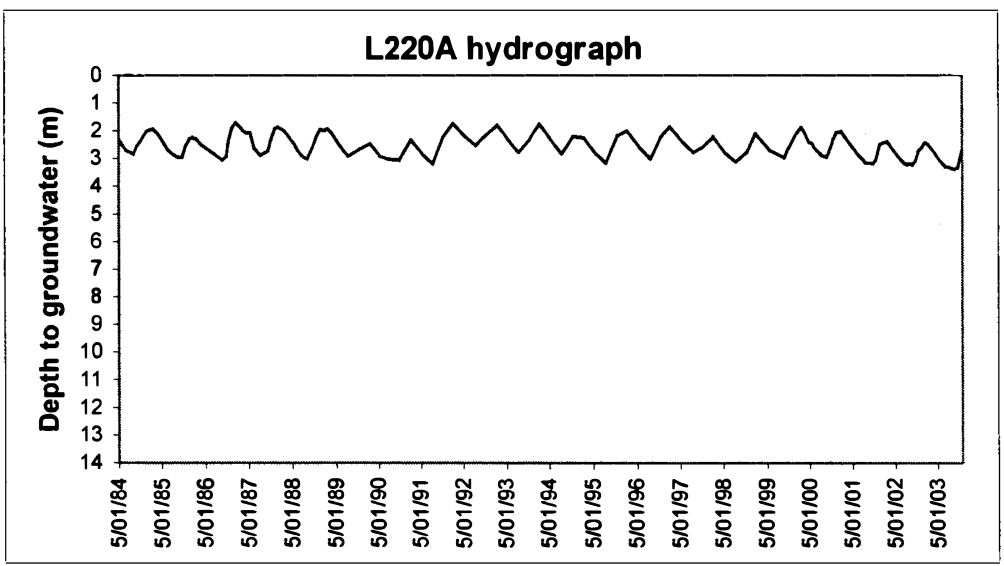
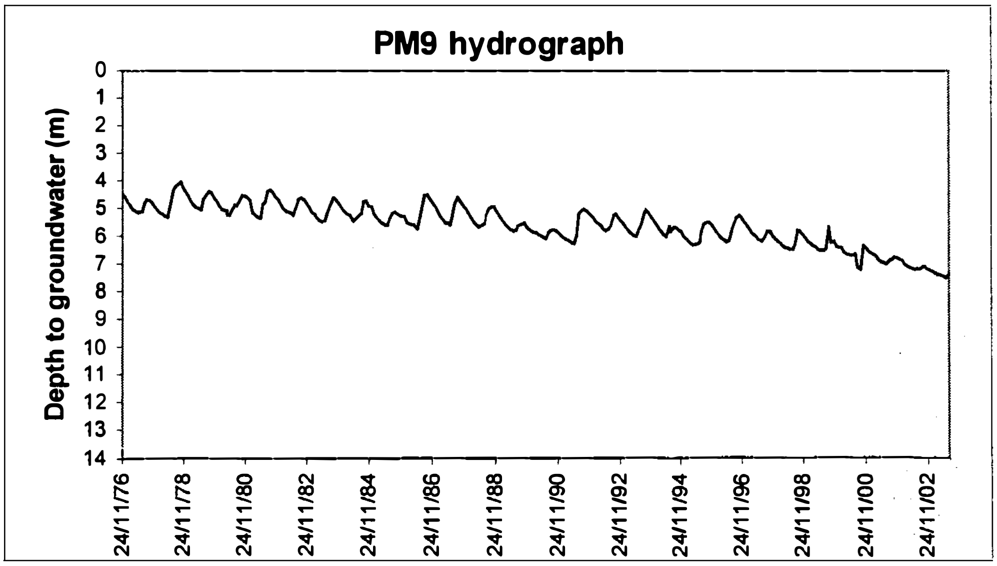


Figure 5.17 **a)** Hydrograph for monitoring bore L220A, located on the Gnangara Mound.
b) Hydrograph for monitoring bore PM9, located on the Gnangara Mound.
c) Hydrograph for monitoring bore GNM6, located on the Gnangara Mound.

b)



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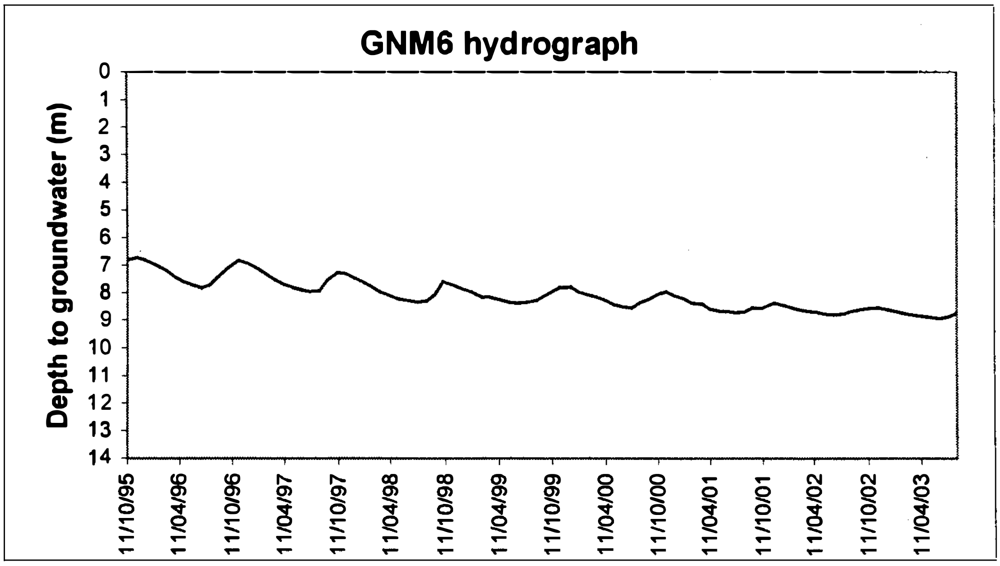


Figure 5.17 **a)** Hydrograph for monitoring bore L220A, located on the Gnangara Mound.
b) Hydrograph for monitoring bore PM9, located on the Gnangara Mound.
c) Hydrograph for monitoring bore GNM6, located on the Gnangara Mound.

5.3.6 Floristical data for 2003 current status sites.

L220A, GNM6 and PM9 are the three current status sites that were used to compare to P50, to examine the impact of the sudden decline event. The vegetation found at these sites was defined as a *Banksia attenuata – Banksia menziesii* woodland, consisting of an open overstorey and a relatively complex understorey. Species were spread across a number of families, with a majority of the species being in the following families: Myrtaceae, Proteaceae, Fabaceae, Cyperaceae, Poaceae, Mimosaceae, Stylidiaceae and Orchidaceae. Other families were also represented and consisted of species that are commonly found in *Banksia attenuata – Banksia menziesii* woodlands, within the Bassendean Sand Dune System. These sites had the same vegetation classification as P50 and they were very close in composition to this site.

For the current status sites, L220A, GNM6 and PM9, a total of 68, 60 and 65 species were observed along the transect respectively (Table 5.8). There were a number of species that were commonly observed throughout the area and these included the following, *Banksia attenuata, Banksia menziesii, Hypocalymma augustifolium, Stylidium brunonianum, Xanthorrhoea preissii, Actinotus glomeratus, Comesperma calymega, Conostephium pendulum, Damperia linearis, Leucopogon conostephioides, Stylidium repens, Adenanthos cygnorum, Eriostemon spicatus, Hibbertia helianthemoides, Tricoryne elatior, Verticordia nitens, Calytrix flavescens, Hibbertia subvaginata, Lobelia tenuior, Lomandra hermaphrodita, Lomandra sericea, Melaleuca seriata, Petrophile linearis, Drosera paleacea, Gonocarpus pithyoides, Lomandra preissii* and *Regelia ciliata* (Table 5.8).

Table5.8 P50, L220A, GNM6 & PM9 % of Total Abundance (Whole Transect)

2003 Data	Root Type	P50	L220A	GNM6	PM9
Shallow-rooted species					
Acacia hugegelii	4a	0.047	0.209	0	0
Acacia litorea	4a	0	0	0.507	0.24
Acacia pulchella	4a	0.103	0.632	2.27	2.69
Actinotus glomeratus	2	0	0	0.82	0.27
Anigozanthos humilis	1	0.24	0	1.589	0.13
Astartea fascicularis	4a	5.851	5.116	7.428	3.24
Austrostipa compressa	1	0.487	0	0	0
Boronia rasmosa	2	0	0.316	0.474	0.27
Burchardia umbellata	1	0	0	0	0.48
Carpobrotus edulis	2	0.047	0	0	0
Comesperma calymega	4a	0.526	0	0	0
Conostylis juncea	1	0	1.631	1.358	0
Corynotheca micranta	1	0	0	0	0.18
Damperia linearis	2	5.688	3.612	4.269	5.57
Desmocladus flexuosus	1	0.101	0	0	0
Dianella divaricata	1	0	0	0.075	0
Drosera erythrorhiza	1	0	0	0.101	0
Drosera paleacea	1	0.041	0	0.455	0
Drosera sp	1	0.422	0	1.134	0.76
Drosera sp (climbing)	1	0.159	0	0	0.53
Elythrahthera brunmis	1	0	0	1.103	0
Euphorbia peplus (1)	1	0.539	0	0	0
Gladiolus caryophyllaceus (1)	1	2.205	1.774	0.224	1.72
Gompholobium tomentosum	4a	0.1	7.106	5.742	1.95
Haemodorum laxum	1	0.05	0	0	0
Haemodorum spicatum	1	0.189	0.197	0	0
Hibbertia helianthemoides	4a	5.98	5.871	3.556	4.88
Hibbertia subvaginata	4a	1.711	4.46	0.203	5.06
Hovea trisperma	4a	0.411	0.522	0.447	0.37
Hypocalymma angustifolium	4a	4.181	0	0	0
Hypochaeris glabra (1)	2	0.697	0	0	0.27
Hypolaena exsulca	1	0.195	0	0	0
Levenhookia stipitata	1	0	0	0	0.48
Lobelia alata	2	0.342	0	0	0
Lobelia tenuior	2	0.041	0	0	0.18
Melaleuca seriata	4a	0.955	0	0	0
Plathytheca galioides	2	0.164	0	0.466	0.4
Regelia ciliata	1	0.937	0	0	0
Sonchus sp (1)	2	0.041	0	0	0
Stylidium brunonianum	2	6.574	2.057	3.966	1.99
Stylidium macrocarpum	2	0	0	0.507	0
Stylidium piliferum	2	0.529	3.762	0.075	1.09
Stylidium repens	2	3.543	0	1.641	0
Stylidium schoenoides	2	0.39	0.948	0	0
Taraxacum officinale (1)	1	0	1.183	0	0
Thysanotus multiflorus	1	0.409	0	0	0
Thysanotus patersonii	1	0.201	0.197	0	0
Thysanotus thyrsoideus	1	0.244	0.209	0	0
Trachymene pilosa	2	1.258	0	0	0
Tricoryne elatior	1	0.974	0	0.304	0
Ursinia anthemoides (1)	2	1.741	0	0	0
Verticordia drummondii	2	1.486	0	0.546	0
Verticordia nitens	2	2.594	0	0.091	2
Xanthosia huegelii	1	0.1	0	0.375	0
Xanthorrhoea preissii	1	11.51	4.172	0.671	6.23
Medium-rooted species					
Astrolomia macrocalyx	6	0	4.534	0.182	0
Unknown 1	6	3.776	1.05	0.304	8.32
Euchilopsis linearis	6	0.182	0	0	0
Hibbertia spicata	6	0	1.101	0	1.48
Lechenaultia floribunda	5	0	0	0.075	0
Leucopogon conostephioides	6	1.554	7.76	6.098	0.36
Leucopogon parviflorus	6	1.745	2.907	1.194	1.55
Leucopogon racemulosus	6	0	0	2.492	0
Leucopogon sprengelioides	6	0.187	5.092	3.074	0
Deep-rooted species					
Acacia barbinervis	4b	0.047	0	0	0
Adenanthos cygnorum	4b	3.237	2.644	0	3.28
Agrostocrinum scabrum	4b	0	0.394	0	0
Allocasurina humilis	4b	0	0.355	0	0

Banksia attenuata	4b	7.589	7.813	4.175	7.69
Banksia ilicifolia	4b	0.696	1.823	0	0
Banksia menziesii	4b	3.777	3.076	3.767	4.94
Beaufortia elegens	4b	2.544	3.612	13.02	19
Bossiaea eriocarpa	4b	0.164	3.121	3.031	1
Calothamnus sanguine	4b	0	0	3.64	1
Calytrix flavescens	4b	7.623	0	0.182	0
Daviesia physodes	3	0.05	0	0	0
Eremaea pauciflora	4b	0.74	5.682	12.48	5.7
Eucalyptus todtiana	4b	0.032	0	0	0
Hardenbergia comptoniana	3	0	0.209	0	0.36
Hibbertia huegleii	4b	0	1.532	1.061	0.91
Jacksonia densiflora	4b	0	0	0.77	0
Jacksonia floribunda	4b	0.074	0	0.331	0.12
Jacksonia sternbergiana	4b	0	0	0.101	0
Kunzia ericifolia	4b	0	0	0	0.85
Nuytsia floribunda	4b	0.419	0.474	0	1.77
Petrophile linearis	3	1.429	2.689	3.059	0.66
Scholtzia involucrata	4b	0.135	0	0	0
Stirlingia laterfolia	4b	0	0.158	0.567	0

(1) represents exotic species

5.3.7 Life history, rooting patterns and tree data for current status sites.

The life history traits at P50, L220A, GNM6 and PM9 in 2003 were examined and specifically looked at native vs. exotic species, plant longevity and life forms (tree, shrub or herb). It was identified from the characteristics in these datasets that all three sites were very similar, with similar proportions of natives vs. exotics, annual and perennial distributions and similar numbers in the various life forms categories (Figures 5.18, 5.19 and 5.20).

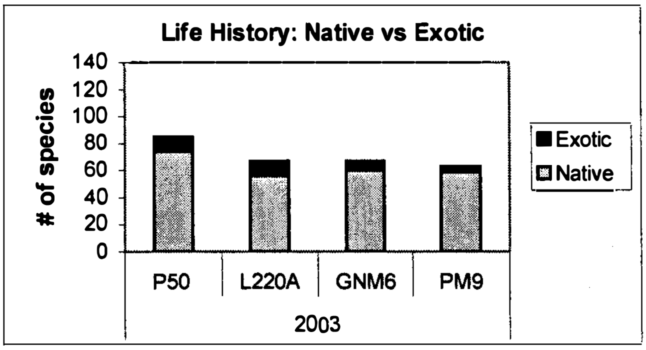


Figure 5.18 P50 Species richness over time. Highlighting - Life History: Total numbers of exotic and native species over time.

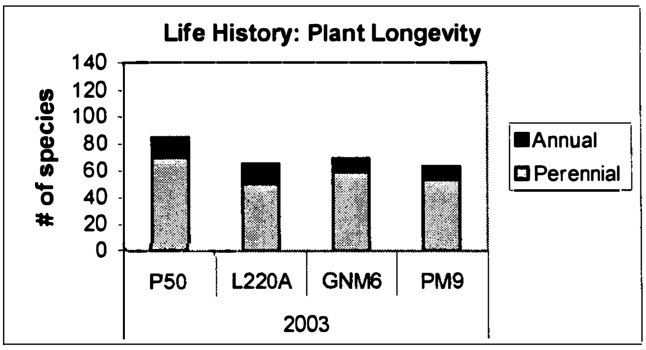


Figure 5.19 P50 Life History: Plant Longevity – Total number of annual and perennial species found at P50 over time.

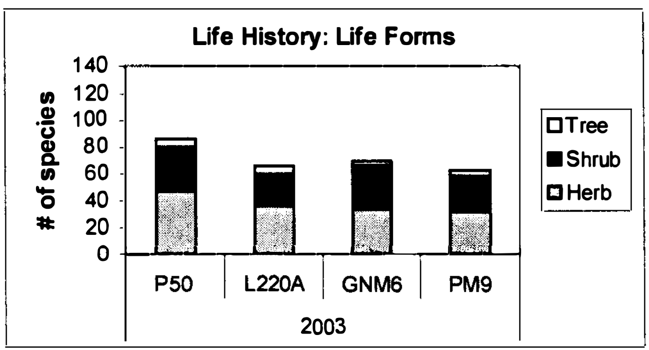


Figure 5.20 P50 Life History: Life Forms – Numbers of species found in varying life forms (Trees, Shrubs and Herbs (which includes grasses) over time at P50.

In addition to studying the life history traits as a way of examining the floristical patterns at the current status study sites, the rooting patterns were also categorized and graphed. The rooting patterns and depths were classified according to Dodd et al. (1984) and have been explained in the previous section.

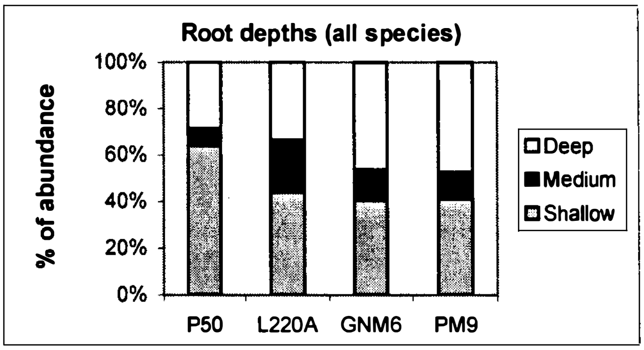
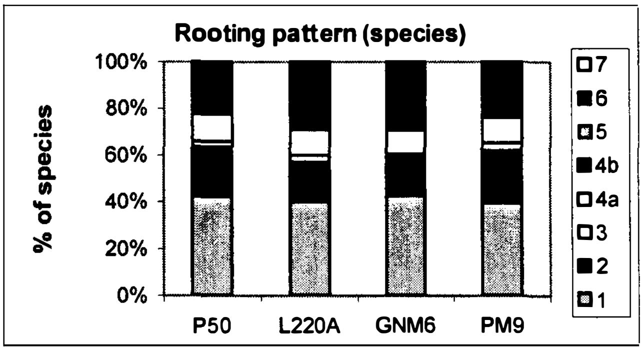


Figure 5.21 Rooting Depths 2003. Rooting depths are classified as shallow (<1m), medium (1<2m) and deep (>2m), and based on data from Dodd et al (1984). All species (natives and exotics).

The rooting depths of P50, L220A, GNM6 and PM9 for 2003 are displayed above. P50 displays a slightly less % of total abundance in the deep-rooted category than the other sites, and a higher % of total abundance in the shallow rooted category. The reason for this difference is due to the drawdown event, where deep-rooted species have not fully recovered to pre drawdown status (Figure 5.21).

The trends observed in the rooting depth categories were also observed in the rooting categories across the sites. It was observed that the sites were very similar in nature in regards to the % of species present at each site, however, the % of total abundance graph indicated that the number of plants observed in the deeper-rooted categories at P50, was less than those observed at the other sites. The reason for this was described earlier (Figure 5.22).

a)



b)

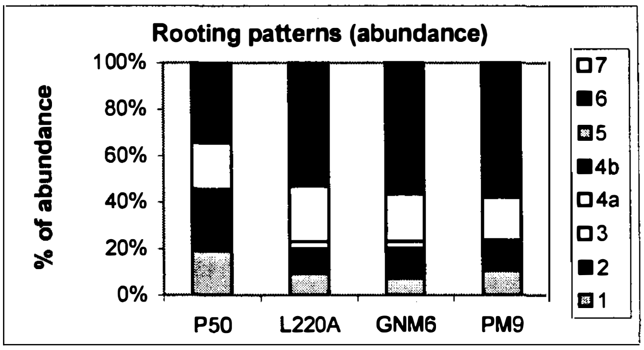
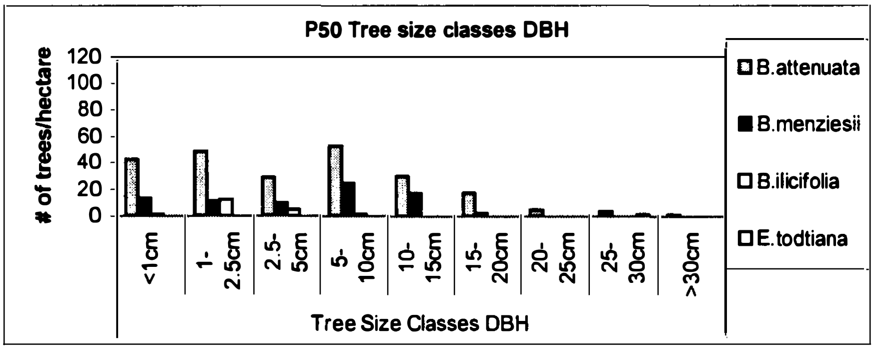


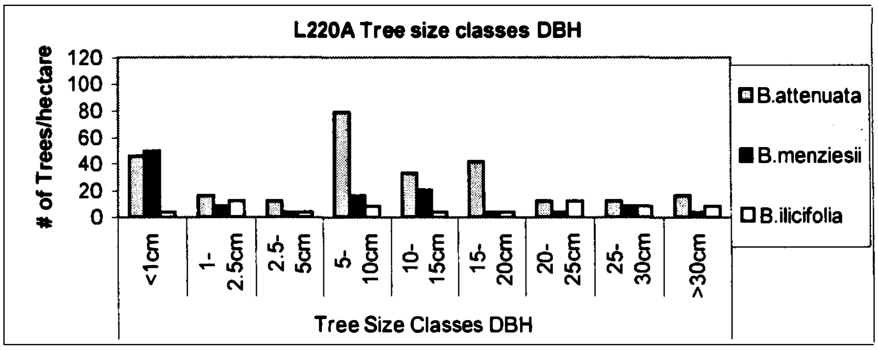
Figure 5.22 **a)** Rooting Patterns 2003. % of species.
b) Rooting Patterns 2003. % of total abundance.

Out of the three current status sites (2003 assessment sites), L220A and GNM6 exhibit very similar trends in tree size class distribution as P50. The trends at P50 show a dominance of trees in the size classes 5-10cm and 10-15 cm. This is seen at the above-mentioned sites, with very few trees seen in the larger older size classes. At PM9 it can be observed that there was a dominance of trees in the smaller two size classes, with a decreasing presence in the larger and older categories. It can be generalised that smaller younger trees, rather than older larger ones, dominated these sites (Figure 5.23).

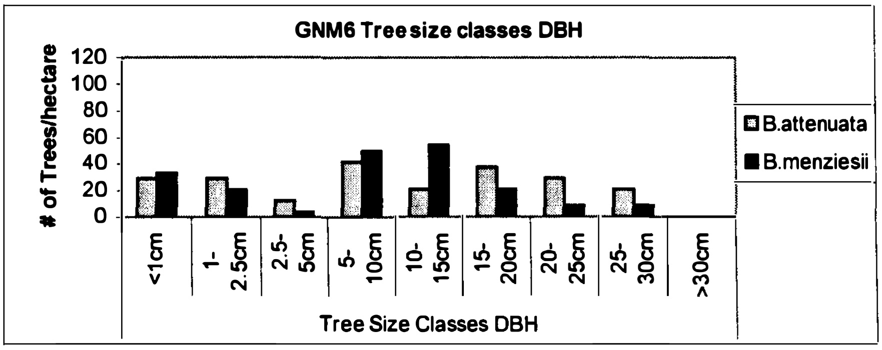
a)



b)



c)



d)

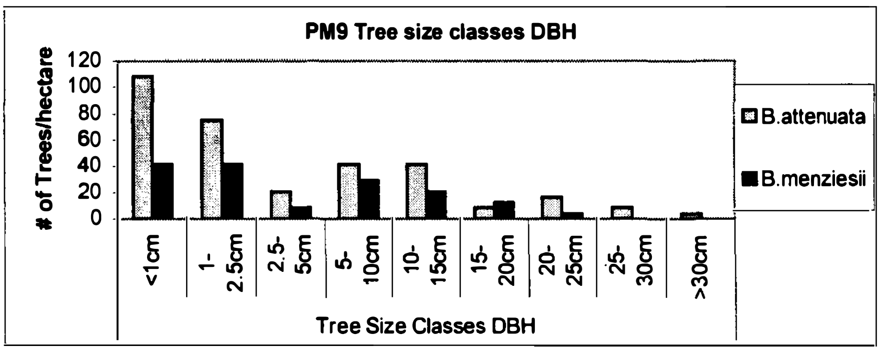


Figure 5.23
a) P50 size class distribution in 2003. Measured DBH.
b) L220A size class distribution in 2003. Measured DBH.
c) GNM6 size class distribution in 2003. Measured DBH.
d) PM9 size class distribution in 2003. Measured DBH.

5.3.8 Indicator species (Havel, 1968) for current 2003 status sites.

The key for Havel's indicator species list has been described earlier in the chapter. The dominant category in 2003, as described by Havel's categories, was those species with maximum development on dry sites (Table 5.9). It can be noted that the species at the current status sites are generally located at the xeric end of the continuum as a result of falling groundwater levels.

Table 5.9 Havel's Species Categories (1968)
Categorising species in relation to site preference.
Indicator Species highlighted in table.
Data in % of Abundance.

Species	Root Type	P50	L220A	GNM6	PM9
Tree Species					
Species of optimum moist sites					
Banksia ilicifolia	4b	0.696	1.823	0	0
Species with a wide tolerance, but with max development on dry sites					
Banksia attenuata	4b	7.589	7.813	4.175	7.691
Banksia menziesii	4b	3.777	3.076	3.767	4.94
Species without clear-cut site preference					
Eucalyptus todtiana	4b	0.033	0	0	0
Nuytsia floribunda	4b	0.419	0.474	0	1.768
Understorey Species					
Species tolerant of excessive wetness					
Euchilopsis linearis	6	0.182	0	0	0
Hypocalymma angustifolium	4a	4.181	0	0	0
Regelia ciliata	4a	0.937	0	0	0
Species of optimum moist sites					
Xanthorrhoea preissii	1	11.51	4.172	0.671	6.234
Species with max development on dry sites					
Beaufortia elegens	4b	2.545	3.612	13.02	19.01
Eremaea pauciflora	4b	0.74	5.682	12.48	5.7
Hibbertia helianthemoides	4a	5.98	5.871	3.556	4.878
Jacksonia floribunda	4b	0.074	0	0.331	0.12
Leucopogon conostephioides	6	1.554	7.76	6.098	0.364
Scholtzia involucrata	4b	0.135	0	0	0
Species without clear-cut site preference					
Bossiaea eriocarpa	4b	0.164	3.121	3.031	1
Calytrix flavescens	4b	7.623	0	0.182	0
Hibbertia subvaginata	4a	1.712	4.46	0.203	5.064

5.3.8.1 Data analysis for current 2003 status sites

At the current status sites non-metric multidimensional scaling (MDS), an ordination technique was employed to investigate multi-temporal patterns or floristic 'trajectories'. The following is representative of the ordination matrices for P50, L220A, GNM6 and PM9, however, instead of examining the transects as a whole, they have been broken down into their individual 20m x 40m quadrats (which have been numbered) (Figure 5.24).

The ordination for these sites demonstrated that there was some overlap between these sites within the % of total abundance ordination. This means that although there are some similarities between the transects, there are also some differences. This difference can be explained through variations in the abundances of a number of smaller herbaceous annuals and perennials (Figure 5.24).

The stress levels observed in the ordination were considered to be relatively low, and are therefore a good representation of the difference between the sites.

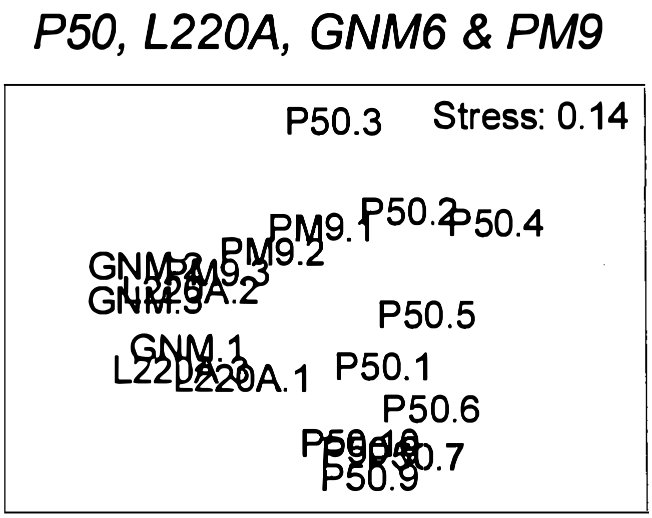


Figure 5.24 Bray-Curtis Similarity Matrix at P50, L220A, GNM6 and PM9 in 2003 (MDS). Percent of total abundance.

5.4 Discussion

Resilience is the ability of a plant community to return to a stable state following a perturbation (Holling, 1996). This definition of resilience examines the changes that occur in a system following a disturbance event, as a way of identifying the degree of a plant community's resilience. In order to assess the resilience of *Banksia* woodland communities to sudden decline events, we have examined a number of other sites in this chapter. The first group of sites consisted of two other long-term monitored sites, and the second group was made up of three current status sites that were used to assess P50's status in 2003.

The native vegetation on the Gnangara Groundwater Mound is a complex continuum of vegetation types, the composition of which is determined by soil conditions, position within the landscape (topography), groundwater depth and soil moisture availability. Monitoring of vegetation transects on the Mound over a 30-year period has shown that the floristic composition is continually changing, with the longer-term transects (established in 1966 or 1976) displaying a greater degree of change (Froend et al., 1999).

The two long-term monitored sites Neaves and Yeal Swamp, were different to P50 floristically, however, this difference was of little significance as the aim of assessing these sites was to compare the changes in trends that had occurred overtime at non-impacted sites, to the changes that had occurred at P50.

Through the comparison of the life history traits observed at P50, Neaves and Yeal Swamp, the trends noted were consistent. This indicated that although the drawdown event affected the vegetation initially, the vegetation trends that have developed over the transects monitored history, would more than likely have occurred regardless of this event. The trends observed in the rooting patterns and rooting depth graphs demonstrating a decrease in the numbers of deep-rooted plants, also indicated that this change in abundance is more likely due to a decrease in groundwater and not necessarily the sudden groundwater decline event. The species discussed refer to the larger slower growing species that take a long time to recover and adjust to groundwater fluctuations.

Floristically P50 has changed, however, all of the long-term monitored sites have also changed. This change has been established through the ordinations that were examined in this chapter. The one-way directional changes observed at P50 has been observed at the other study sites, indicating that it is not the drawdown event that has caused the changes noted, but a combination of gradual changes within the environment and reduced groundwater availability, due to a lowering of the watertable.

The total abundance of plants at all of the sites is decreasing steadily, and was observed in all attributes. It has also been observed that the long-term monitored sites exhibit similar trends in the proportion of their species found in the varying rooting types and patterns, indicating that they have all undergone similar conditions and are in a similar state. Although this does not mean that the sites themselves are similar in nature, because due to topographical differences they are not, it simply means that all have changed similarly due to a common environmental influence, a lowering of the watertable.

The fluctuations in the watertable at the 2003 current status sites demonstrated a normal seasonal trend and no evidence of a drawdown event is evident. This means that although these sites are relatively close to P50 they were located far enough away not to have been affected by the abstraction at P50 when the abstraction bore was commissioned. The comparison of these sites to P50 demonstrated a close relationship, both floristically and functionally.

Through comparison of the current status sites and P50 in an ordination matrix, it was observed that P50 had a high degree of floristic similarity. This is also an indication that P50 has recovered to a state similar to what it would be expected to be in, had it not undergone a sudden decline episode. This is an important point as it supports the hypothesis that the *Banksia* woodlands of the Gnangara Mound are resilient to a large degree to such an event. Although there were some differences in this ordination, the Gnangara Mounds vegetation is very diverse and different abundance and composition of species can occur, even with only a small change in site conditions.

All of the results indicate that the drawdown event at P50 is only responsible for the changes that occurred immediately following the event, and that the long-term changes in the woodland were mainly due to the environmental changes that have occurred since and reduced recharge that caused a lowering of the watertable. Increasing outside pressures from other resources accessing groundwater are also responsible for the decreasing watertable levels.

Reducing the impacts of drawdown on the native *Banksia* woodland vegetation surrounding groundwater production bores and wellfields is an important task for managers of groundwater resources. The understanding of such processes and events is essential for the maintenance of groundwater levels within limits necessary to support ecological water requirements (Groom et al., 2000). This chapter has examined the resilience of *Banksia* woodlands to drawdown and has presented data that supports the notion that *Banksia* woodlands are resilient to drawdown and that they do possess the potential to recovery after such an event.

Chapter 6

Synthesis

6.1 Synthesis

The aim of this chapter is to assess the resilience of *Banksia* woodlands to sudden groundwater decline events, by incorporating the main results obtained from the three specific aims in the project. These were:

1. **Identify and describe the hydrological and climatic regimes associated with sudden decline events and recovery of a *Banksia* woodland community.**

2. **Examine the floristic changes and recovery in a *Banksia* woodland community impacted by a sudden groundwater decline event.**

3. **Assess the resilience of *Banksia* woodland communities to sudden groundwater decline episodes.**

The Bassendean dune system forms a part of the northern Swan Coastal Plain, under which lies a large shallow unconfined aquifer, the Gnangara Groundwater Mound. Groundwater and soil moisture levels have been gradually decreasing in most areas of the Gnangara Mound since the 1970s as a combined result of a number of years of below average rainfall, increased groundwater abstraction and increased use by various groundwater users (Davison, 1995). The Gnangara Mound is the largest and most important shallow underground water resource in the Perth region and it supplies substantial amounts of water to meet Perth's current water demands, and is, therefore, a vital resource to the entire Perth and surrounding regions (Heddle, 1986).

In conjunction with this use, the Gnangara Mound also represents a significant water resource to native phreatophytic (groundwater dependent) vegetation. To safeguard terrestrial vegetation, groundwater levels must be maintained to allow plants access to water that is required for their growth and continued existence. In many areas throughout the Gnangara Mound, studies by Havel and Mattiske have indicated that watertable drawdown has a high potential to impact on phreatophytic vegetation. A lowering of the watertable level and the climatic changes over the last 30 years has resulted in measured changes in community composition to more drought tolerant species. This was observed at the long-term monitored sites that were examined as part of this study (Neaves and Yeal Swamp). The survival of groundwater dependent vegetation to drawdown depends on a species' capacity to adjust to reduced water availability.

The impact and consequence of groundwater drawdown on phreatophytic vegetation has been discussed, and ranges from gradual changes in community composition over decades, to sudden and extensive vegetation deaths (Groom, Froend and Mattiske, 2000a). Gradual changes in Banksia woodlands due to reduced soil water (groundwater and unsaturated zone moisture) availability has been observed on the Gnangara Mound over a relatively long period of time, along with a gradual change in species composition and community structure (Froend et al 2000a). A shift in species composition towards the xeric end of the floristic continuum was observed at all of the long-term monitored sites studies as part of this project. Overstorey species that cannot tolerate long periods of reduced soil water availability have slowly died-out and have been replaced by more drought-tolerant species.

Chapter three addressed the first aim by identifying the changes in the climatic and hydrological data before and after the drawdown at the P50 production bore. The hydrological changes observed across all study sites indicated that there is a general trend on the Gnangara Mound that appears to indicate a lowering of the watertable across the Gnangara Mound as a whole. This hydrological trend appears to be more responsible for the changes that have occurred throughout the Gnangara Mound, than specific localized drawdown events as experienced at P50. Although this event at P50 had serious implication to the localized vegetation at the time, the trends that have been observed in the floristics indicate that the current status of P50 is not too dissimilar to what has been observed at the other study sites.

The annual hydrological cycle observed at the P50 monitoring bore appears to be typical of the hydrology of Western Australia's Swan Coastal Plain, where the groundwater levels and recharge patterns are controlled by the seasonality and amount of rainfall received (Allen, 1981). The pattern of maximum groundwater depth in March to April resulting from a 3-4 month period of summer drought and minimum depth to groundwater and main recharge occurring during the winter months (April to October) (as described by Allen, 1981), was observed at P50 and the other study sites.

The P50 production bore has experienced climatic conditions similar to those experienced across the Swan Coastal Plain, however, the changes that have occurred across this region have contributed to declining groundwater levels throughout the Gnangara Mound. Perth has experienced hotter drier summers, which has resulted in low summer recharge, and consequently, species are more dependent on groundwater during the dry months. Winters across the Swan Coastal Plain have also been observed to be drier with decreasing annual rainfall levels. This has resulted in decreased recharge to groundwater aquifers, in particular, the Gnangara Mound. This has contributed to the declining watertable levels over the past 20 to 30 years.

The changes associated with drawdown in *Banksia* woodland communities was discussed in chapter four. This chapter concluded that there has been a significant change in the species' composition and abundance at P50, however, the trend observed at this site were relatively linear, with a dip in these trends surrounding the drawdown event. This indicated that although the drawdown event influenced the vegetation immediately preceding the decline in the watertable, the changes in species composition and abundance throughout the transect over time could be attributed to the overall decline in groundwater levels. This decline is associated with environmental changes and increased pressure on groundwater due to consumption by external sources.

Results from the long-term vegetation data indicated that there has been a change in plant species, and a decrease in plant abundances within the vegetation transects monitored as part of this study. The species composition within the long-term monitored transects was observed to be changing to the xeric end of the floristic continuum, and this was supported by the indicator species, that were defined by Havel (1968), and were present in the transects.

Preceding the drawdown event at P50, huge changes were observed in the floristics, however, the vegetation appeared to recover within two following monitoring periods.

These changes were the result of a number of small herbaceous plant species that were extremely prevalent at the time of monitoring. The trends at P50 then continued on a one-directional linear relationship away from its originally observed state. It was this trend over time that was identical to the sites that had not undergone a drawdown event, and indicated that P50 is in a similar state now to what would be in if the sudden decline event had not occurred.

In addition to examining the long-term monitored sites, a number of current status sites (2003) were studied. These sites were in close proximity to P50 and contained similar floristical attributes. The results from the comparison of P50 to these sites revealed that they are fairly similar in structure and composition to P50. This indicated that although these sites did not undergo a groundwater decline event, they have changed at a similar rate to P50. This comparison was important as it suggested that the changes observed at P50 over its monitored history were natural changes as a response to a gradual changing of the watertable and not the result of the drawdown event that occurred.

The vegetation monitoring program on the Gnangara Mound is a long-term floristic plan developed by the Waters and Rivers Commission, which covers transition in vegetation types between dune crests and dune slopes. This vegetation database is part of the overall plan for management of the Gnangara Mound and it's water reserves. However, constant monitoring of hydrology and climatic trends is required to determine any long or short-term changes in hydrology that may result in a sudden decline event. Reducing the impact of drawdown on the native *Banksia* woodlands surrounding groundwater production bores and wellfields is an important task for managers of this groundwater resource. The understanding of such processes and events is essential for the maintenance of groundwater levels within limits necessary to support ecological water requirements (Groom et al., 2000). In the future, reducing or completely ceasing abstraction following years of poor recharge may reduce the risk of such a disturbance from occurring in the future.

In conclusion, the research document in this thesis has used both experimental data and data derived from the existing Waters and Rivers Commission's long-term vegetation database. From the results, it can be concluded that on the whole, *Banksia* woodland communities are resilient to large-scale drawdown events and appear to recover to an equivalent state if time permits. Thus, notwithstanding this drawdown event, the current state of the *Banksia* woodland would have eventuated regardless, due to environmental and climatic changes.

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Appendix

Appendix 1

Table : Species Abundance occurring within the Yeal Swamp transect over time.

Rooting depths are classified as shallow (<1m), medium (1<2m) and deep (>2m) and based on the data from Dodd et al. (1984).

Species	Root Type	Yeal Swamp 1987	1993	1996	2002
Alexgeorgea nitens	1	0	8	12	1
Amphipogan turbinatus	1	2	1	1	0
Anigozanthos humilis	1	1	0	0	0
Anigozanthos manglessii	1	1	1	0	0
Anigozanthos sp.	1	0	2	0	0
Arnocrinum preissii	1	1	0	1	0
Austrostipa spp	1	2	1	0	0
Avena fatua (1)	1	0	1	0	0
Briza maxima (1)	1	4	1	0	2
Burchardia umbellata	1	0	7	0	1
Centaurium erythraea (1)	1	1	1	1	0
Conostylis aculeata	1	15	17	18	12
Conostylis juncea	1	2	5	2	3
Corynotheca micrantha	1	3	4	2	0
Daucus glochidiatus	1	0	3	0	4
Desmocladus flexuosus	1	12	17	18	17
Drosera paleacea	1	0	0	1	0
Drosera spp	1	1	0	0	0
Haemodorum sp.	1	1	0	0	0
Hypolaena exsulca	1	0	7	5	1
Johnsonia pubescens	1	1	1	1	0
Lagenophora huegelii	1	0	0	0	2
Lepidosperma gracile	1	1	0	0	0
Lepidosperma sp.	1	0	4	0	0
Lepidosperma squamatum	1	4	10	10	2
Lepidosperms tenue	1	3	0	0	0
Levenhookia pusilla	1	0	0	0	1
Levenhookia stipitata	1	0	16	0	13
Lomandra caespitosa	1	0	0	2	1
Lomandra drummondii	1	0	1	0	0
Lomandra hermaphrodita	1	15	16	14	4
Lomandra sericea	1	1	1	1	1
Lomandra spp	1	1	0	0	0
Lyginia barbata	1	10	14	16	1
Mesomelaena stygia	1	4	5	5	0
Patersonia occidentalis	1	6	10	8	3
Phylebocarya ciliata	1	9	13	8	5
Poaceae sp.	1	0	0	0	1
Schoenus curvifolius	1	23	27	23	17
Tetrarrhena laevis	1	0	0	1	1
Thelymitra crinita	1	0	1	0	0
Thysanothus spp	1	1	0	0	0
Thysanotus patersonii	1	1	0	0	0
Vulpia myuros (1)	1	0	0	1	1
Xanthorrhoea gracilisi	1	1	0	0	0
Xanthorrhoea preissii	1	75	87	87	86
Xanthosia huegelii	1	11	8	2	3
Total		**213**	**290**	**240**	**183**
Boronia ramosa	2	95	4	22	32
Damperia linearis	2	2	2	3	2
Euchiton sphaericus	2	1	0	0	0
Gompholobium confertum	2	0	0	0	1
Hyalosperma cotula	2	2	0	0	2
Hypolaena glabra (1)	2	1	4	2	3
Isotropis cuneifolia	2	0	2	1	1
Lobelia tenior	2	0	2	1	9
Pterochaeta paniculata	2	2	2	0	4
Siloxerus humifusus	2	0	1	0	5

Sonchus sp. (1)		2	0	2	0	2
Stylidium brunonianum		2	13	9	4	14
Stylidium calcaratum		2	2	0	0	1
Stylidium crossocephalum		2	2	3	1	0
Stylidium piliferum		2	0	2	1	2
Stylidium repens		2	13	21	19	17
Stylidium schoenoides		2	1	1	0	0
Stylidium spp		2	1	0	0	0
Trachymene pilosa		2	0	0	0	1
Ursinia anthemoides (1)		2	0	0	0	1
	Total		**135**	**55**	**54**	**97**
Petrophile linearis		3	59	55	38	42
Petrophile macrostachya		3	4	4	5	7
Scaevola canescens		3	0	1	0	0
	Total		**63**	**60**	**43**	**49**
Heminadra pungens		5	110	47	61	20
	Total		**110**	**47**	**61**	**20**
Andersonia lehmanniana		6	31	18	5	0
Croninia kingiana		6	2	2	2	0
Kennedia prostrata		6	2	3	0	1
Leucopogon polymorphus		6	124	118	56	17
Leucopogon propinquus		6	2	2	2	1
Leucopogon conostephioides		6	107	177	143	31
Leucopogon sp.		6	1	0	0	0
	Total		**269**	**320**	**208**	**50**
Acacia huegelii		4a	24	22	9	0
Acacia pulchella		4a	307	39	17	33
Acacia stenoptera		4a	7	8	6	1
Aotus procumbens		4a	106	29	14	1
Calytrix angulata		4a	31	48	45	24
Comesperma flavum		4a	1	22	15	32
Gompholobium tomentosum		4a	171	145	67	33
Hibbertia hypericoides		4a	188	156	181	132
Hibbertia subvaginata		4a	238	200	171	137
Hypocalymma angustifolium		4a	28	28	34	23
Macrozamia riedlei		4a	5	5	5	4
Melaleuca preissiana		4a	62	75	64	50
Melaleuca scabra		4a	1	1	2	1
Nemcia capitata		4a	75	85	46	9
Pericalymma ellipticum		4a	29	54	50	55
Philotheca spicata		4a	11	23	13	2
Regelia inops		4a	356	651	669	150
	Total		**1640**	**1591**	**1408**	**687**
Acacia saligna		4b	0	0	1	1
Adenanthos cygnorum		4b	177	157	159	57
Allocasuarina humilis		4b	1	1	1	0
Banksia attenuata		4b	213	634	342	218
Banksia ilicifolia		4b	15	23	20	30
Banksia menziesii		4b	200	489	348	174
Bossiaea eriocarpa		4b	194	218	112	31
Calothamnus sanguineus		4b	144	113	104	80
Calytrix flavescens		4b	99	84	63	38
Eremaea asterocarpa		4b	3	3	2	2
Eucalyptus rudis		4b	93	119	77	71
Eucalyptus todtiana		4b	70	83	83	91
Hibbertia huegelii		4b	38	35	38	28
Jacksonia furcellata		4b	81	92	79	14
Jacksonia sternbergiana		4b	22	6	5	2
Kunzea ericifolia		4b	784	880	721	658
Nuytsia floribunda		4b	34	20	18	46
Persoonia comata		4b	10	9	11	4
Scholtzia involucrata		4b	314	266	225	172
Stirlingia latifolia		4b	16	19	14	13
Synaphea spinulosa		4b	12	10	13	3
Verticordia nitens		4b	119	137	124	93
	Total		**2639**	**3398**	**2560**	**1826**

(1) represents exotic species

Appendix 2

GNM6 2003

Abundance	**Plot 1 Number**	**Plot 1 % Cover**	**Plot 2 Number**	**Plot 2 % Cover**	**Plot 3 Number**	**Plot 3 % Cover**
Acacia barbinervis						
Acacia hugegelii						
Acacia litorea			5	0.625		
Acacia pulchella	28	4.25			2	0.25
Actinotus glomeratus	11	0.875				
Adenanthos cygnorum						
Agrostocrinum scabrum						
Aira caryophyllea *						
Alexgeorgea nitens		4.25		4		3.75
Allocasurina humilis						
Amphipogan turbinatus						0.375
Angallis arvensis *						
Anigozanthos humilis			4	0.5	13	0.625
Astartea fascicularis	43	3.75	12	2.25	33	5.75
Astrolomia macrocalyx					2	0.25
Austrostipa compressa						0.25
Avena fatua *						
Banksia attenuata	1	0.125				
Banksia ilicifolia						
Banksia menziesii					2	0.125
Beaufortia elegens	31	6.75	50	7.25	62	8
Boronia rasmosa	5	0.5	1	0.125		
Bossiaea eriocarpa	23	5.75	4	1.125	10	1.5
Briza maxima *				0.25		
Bromus madritensis*						
Burchardia umbellata						
Caladenia sp						
Calytrix flavescens					2	0.5
Calothamnus sanguine	15	4.5	15	1	11	1.375
Carpobrotus edulis						
Cassytha flava						
Cassytha racemosa						
Cassytha sp						0.75
Chamaexeros serra						
Comesperma calymega						
Conostephium pendulum						
Conostylis juncea	6	0.375		1.75	10	0.125
Corynotheca micranta						
Cyrtostylis sp						
Damperia linearis	40	1.75	10	0.375	3	0.125
Dasypogon bromeliifolius						
Daviesia physodes						
Desmocladus flexuosus		0.75		1		1.25
Dianella divaricata	1	0.125				
Drosera erythrorhiza			1	0.125		
Drosera paleacea					5	0.375
Drosera sp	3	0.25			10	0.125
Drosera sp (climbing)						
Ehrharta calycina *						
Elythrahthera brunmis			1	0.125	11	0.625
Eremaea pauciflora	19	11.25	75	33	38	11.5
Eriostemon spicatus						
Eucalyptus todtiana						
Euchilopsis linearis						
Euphorbia peplus *		0.375		0.125		
Gladiolus caryophyllaceus *	3	0.25				
Gompholobium tomentosum	33	3.75	18	2.25	16	2
Gonocarpus cordiger						
Haemodorum laxum						
Haemodorum spicatum						
Hardenbergia comptoniana						
Hibbertia helianthemoides	6	0.75	19	2.75	13	1.75
Hibbertia huegleii	13	2.25			1	0.125
Hibbertia spicata						
Hibbertia subvaginata			2	0.25		
Hovea trisperma	6	1				
Hyalosperma cotula						
Hypocalymma angustifolium						
Hypochaeris glabra *						
Hypolaena exsulca						
Isolepis marginata *		0.25				
Jacksonia floribunda	2	1.75			2	0.25
Jacksonia densiflora			4	2	4	2.5

Jacksonia sternbergiana			1	0.5		
Johnsonia acaulis						
Juncus pallidus						
Kunzia ericifolia						
Laxmannia ramosa						0.125
Laxmannia squarrosa						
Lechenaultia floribunda	1	0.25				
Lepidosperma squamatum (narrow form)		0.5				1.125
Leporella fimbriata						
Leucopogon conostephioides	39	6.5	18	4.75	15	5
Leucopogon parviflorus	8	2.75	5	1.5	1	0.125
Leucopogon racemulosus			21	4.75	4	0.75
Leucopogon sprengelioides	13	2.5	1	0.5	22	3.25
Levenhookia stipitata						
Lobelia alata						
Lobelia tenuior						
Lomandra caespitosa		0.25		2.25		1.25
Lomandra hermaphrodita		1		0.5		0.25
Lomandra preissii		0.5				
Lomandra sericea		0.5		0.5		1.375
Loxocarya flexuosa						
Lyginia barbata		5.25		3.5		2.5
Melaleuca scabra						
Melaleuca seriata						
Mesomelaena stygia						
Microlaena stipoides						
Mitrasacme paradoxa						
Monotaxis occidentalis						
Nemcia capitata						
Nuytsia floribunda						
Orchidaceae sp (enamel orchid)						
Patersonia occidentalis		2		0.75		1.25
Pennisetum villosum*						
Pentaschistis thumbergii*				0.5		
Petrophile linearis	14	3.75	10	1.75	11	2.5
Philotheca spicata						
Phlebocarya ciliata						
Phyllangium paradoxum						
Pithocarpa pulchella						
Plathytheca galioides			1	0.25	4	1
Poa porphyroclados						
Podotheca chrysantha						
Podotheca gnaphalioides						
Regelia ciliata						
Rumex crispus		0.125				
Schoenus curvifolius						
Schoenus pedicellatus						
Scholtzia involucrata						
Sonchus sp *						
Stirlingia laterfolia			2	1.5	4	0.5
Stylidium brunonianum	21	0.75	12	0.75	13	0.5
Stylidium junceum						
Stylidium macrocarpum			5	0.25		
Stylidium piliferum	1	0.125				
Stylidium repens	22	2.25		1.75		0.5
Stylidium schoenoides						
Taraxacum officinale*						
Thysanotus multiflorus						
Thysanotus patersonii						
Thysanotus thyrsoideus						
Trachymene pilosa						
Tricoryne elatior			3	0.25		
Ursinia anthemoides *		0.75		0.75		0.375
Verticordia drummondii					6	1.25
Verticordia nitens					1	0.25
Waitzia suaveolens		1				0.375
Xanthorrhoea gracilis						
Xanthorrhoea preissii	9	5				
Xanthosia huegelii			1	0.125	3	0.25
Unknown 1		0.125	3	0.25		

Appendix 3

L220A/C 2003

Abundance	**Plot 1**		**Plot 2**		**Plot 3**	
	Number	**% Cover**	**Number**	**% Cover**	**Number**	**% Cover**
Acacia barbinervis						
Acacia hugegelii					2	0.5
Acacia litorea						
Acacia pulchella			4	1.5		
Actinotus glomeratus						
Adenanthos cygnorum	11	3.25	3	0.75		
Agrostocrinum scabrum	2	0.125				
Airà caryophyllea *				1.125		0.625
Alexgeorgea nitens		5		6		2.25
Allocasurina humilis	1	0.75	1	1.5		
Amphipogan turbinatus						
Angallis arvensis *						
Anigozanthos humilis						
Astartea fascicularis	14	0.875	3	0.5	18	2.25
Astrolomia macrocalyx	11	2.25	11	3.25	6	1.25
Austrostipa compressa						
Avena fatua *						
Banksia attenuata						
Banksia ilicifolia						
Banksia menziesii						
Beaufortia elegens	1	1	15	1.75	10	1.5
Boronia rasmosa			2	0.5		
Bossiaea eriocarpa	2	0.25	8	1.5	14	2.5
Briza maxima *		1.75		0.5		0.5
Bromus madritensis*		0.5				
Burchardia umbellata						
Caladenia sp						
Calytrix flavescens						
Calothamnus sanguine						
Carpobrotus edulis						
Cassytha flava						
Cassytha racemosa		2				0.75
Cassytha sp						
Chamaexeros serra						
Comesperma calymega						
Conostephium pendulum						
Conostylis juncea			9	0.75	2	0.125
Corynotheca micranta						
Cyrtostylis sp						
Damperia linearis	13	6.25	2	0.125	7	0.375
Dasypogon bromeliifolius				2		2.75
Daviesia physodes						
Desmocladus flexuosus						
Dianella divaricata						
Drosera erythrorhiza						
Drosera paleacea						
Drosera sp						
Drosera sp (climbing)						
Ehrharta calycina *						
Elythrahthera brunmis						
Eremaea pauciflora	7	4.25	14	4	20	9.25
Eriostemon spicatus						
Eucalyptus todtiana						
Euchilopsis linearis						
Euphorbia peplus *		1.25		0.5		0.5
Gladiolus caryophyllaceus *	5	0.5	3	0.125	3	0.375
Gompholobium tomentosum	11	1.75	20	3.75	17	2.5
Gonocarpus cordiger						
Haemodorum laxum						
Haemodorum spicatum	1	0.125				
Hardenbergia comptoniana					2	0.75
Hibbertia helianthemoides			16	1.75	32	6.25
Hibbertia huegleii	3	0.5			9	1.75
Hibbertia spicata			3	0.5	6	1.25
Hibbertia subvaginata	13	2	12	1.75		
Hovea trisperma					5	0.5
Hyalosperma cotula						
Hypocalymma angustifolium						
Hypochaeris glabra *						
Hypolaena exsulca				0.75		
Isolepis marginata *						
Jacksonia floribunda						
Jacksonia densiflora						

Jacksonia sternbergiana						
Johnsonia acaulis						
Juncus pallidus		1				
Kunzia ericifolia						
Laxmannia ramosa						
Laxmannia squarrosa						
Lechenaultia floribunda						
Lepidosperma squamatum (narrow form)		1		1.75		1.5
Leporella fimbriata						
Leucopogon conostephioides	13	2	19	3	21	3
Leucopogon parviflorus	2	0.75	4	1.75	18	4
Leucopogon racemulosus						
Leucopogon sprengelioides	8	1.5	11	2	17	4
Levenhookia stipitata						
Lobelia alata						
Lobelia tenuior						
Lomandra caespitosa						0.25
Lomandra hermaphrodita		0.25				0.75
Lomandra preissii						
Lomandra sericea		0.5		0.25		1.25
Loxocarya flexuosa		0.75		1		2.25
Lyginia barbata		2.25		20		9.5
Melaleuca scabra						
Melaleuca seriata						
Mesomelaena stygia						
Microlaena stipoides						
Mitrasacme paradoxa						
Monotaxis occidentalis						
Nemcia capitata						
Nuytsia floribunda						
Orchidaceae sp (enamel orchid)						
Patersonia occidentalis		2.25		1.75		4.25
Pennisetum villosum*				0.25		
Pentaschistis thumbergii*		5		0.25		
Petrophile linearis	3	1	6	1.25	11	2.5
Philotheca spicata						
Phlebocarya ciliata						
Phyllangium paradoxum						
Pithocarpa pulchella						
Plathytheca galioides						
Poa porphyroclados		1.75		1		0.125
Podotheca chrysantha		0.375		0.375		0.25
Podotheca gnaphalioides		0.5				
Regelia ciliata						
Rumex crispus						
Schoenus curvifolius		0.25				0.75
Schoenus pedicellatus						
Scholtzia involucrata						
Sonchus sp *				0.75		
Stirlingia laterfolia			1	0.25		
Stylidium brunonianum	3	0.125	2	0.125	11	0.25
Stylidium junceum						
Stylidium macrocarpum						
Stylidium piliferum					36	1.25
Stylidium repens		2.25		2.875		3
Stylidium schoenoides			6	0.25		
Taraxacum officinale*	6	0.125				
Thysanotus multiflorus						
Thysanotus patersonii	1	0.125				
Thysanotus thyrsoideus					2	0.125
Trachymene pilosa						
Tricoryne elatior						
Ursinia anthemoides *				0.5		0.5
Verticordia drummondii						
Verticordia nitens						
Waitzia suaveolens		0.25		0.125		0.25
Xanthorrhoea gracilis						
Xanthorrhoea preissii	10	13.75	4	5.5	15	12.25
Xanthosia huegelii						
Unknown 1			4	0.75	4	0.5

Appendix 4

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Abundance	**Plot 1**		**2**		**3**	
	Number	**% Cover**	**Number**	**% Cover**	**Number**	**% Cover**
Acacia barbinervis						
Acacia hugegelii						
Acacia litorea					2	0.25
Acacia pulchella			4	0.875	18	3.75
Actinotus glomeratus			2	0.25		
Adenanthos cygnorum	3	0.25	16	1.75	5	10
Agrostocrinum scabrum						
Aira caryophyllea *						
Alexgeorgea nitens				0.75		0.25
Allocasurina humilis						
Amphipogan turbinatus						1
Angallis arvensis *						
Anigozanthos humilis			1	0.125		
Astartea fascicularis					27	2.5
Astrolomia macrocalyx						
Austrostipa compressa		0.625		0.25		0.375
Avena fatua *						
Banksia attenuata						
Banksia ilicifolia						
Banksia menziesii						
Beaufortia elegens	14	3.5	65	23.25	65	37
Boronia rasmosa			2	0.75		
Bossiaea eriocarpa			3	0.5	5	1.75
Briza maxima *						
Bromus madritensis*						
Burchardia umbellata					4	0.25
Caladenia sp						
Calytrix flavescens						
Calothamnus sanguine			3	1.25	5	1.5
Carpobrotus edulis						
Cassytha flava						
Cassytha racemosa						
Cassytha sp						
Chamaexeros serra						
Comesperma calymega						
Conostephium pendulum						
Conostylis juncea				0.25		0.5
Corynotheca micranta	1	0.125				
Cyrtostylis sp						
Damperia linearis			31	0.5	12	0.5
Dasypogon bromeliifolius		7.25		1.5		
Daviesia physodes						
Desmocladus flexuosus		0.625		3		2.25
Dianella divaricata						
Drosera erythrorhiza						
Drosera paleacea						
Drosera sp			3	0.125	3	0.125
Drosera sp (climbing)			4	0.25		0.125
Ehrharta calycina *						
Elythrahthera brunmis						
Eremaea pauciflora	16	6.75	11	1.75	11	3.5
Eriostemon spicatus						
Eucalyptus todtiana						
Euchilopsis linearis						
Euphorbia peplus *		0.875		0.625		0.625
Gladiolus caryophyllaceus *	1	0.125	7	0.375	5	0.25
Gompholobium tomentosum	1	0.25	7	1.5	7	1.25
Gonocarpus cordiger						
Haemodorum laxum						
Haemodorum spicatum						
Hardenbergia comptoniana	2	0.125				
Hibbertia helianthemoides	9	1.5	9	0.875	17	2.25
Hibbertia huegleii	5	0.625		0.25		
Hibbertia spicata			3	0.5	9	1
Hibbertia subvaginata	12	3.5	9	2	14	1.75
Hovea trisperma			1	0.125	2	0.5
Hyalosperma cotula						
Hypocalymma angustifolium						
Hypochaeris glabra *			2	0.125		
Hypolaena exsulca						
Isolepis marginata *						
Jacksonia floribunda					1	0.5
Jacksonia densiflora						

Jacksonia sternbergiana						
Johnsonia acaulis						
Juncus pallidus						
Kunzia ericifolia	1	0.5	5	0.25		
Laxmannia ramosa						
Laxmannia squarrosa						
Lechenaultia floribunda						
Lepidosperma squamatum (narrow form)		1		0.25		
Leporella fimbriata						
Leucopogon conostephioides	2	0.5				
Leucopogon parviflorus	5	2	3	0.75	2	0.5
Leucopogon racemulosus						
Leucopogon sprengelioides						
Levenhookia stipitata	2	0.125			1	0.125
Lobelia alata						
Lobelia tenuior	1	0.125				
Lomandra caespitosa				0.5		
Lomandra hermaphrodita		0.5				0.5
Lomandra preissii				0.125		
Lomandra sericea		1.375		0.375		0.125
Loxocarya flexuosa						
Lyginia barbata		0.5				3
Melaleuca scabra						
Melaleuca seriata						
Mesomelaena stygia						
Microlaena stipoides						0.75
Mitrasacme paradoxa						
Monotaxis occidentalis						
Nemcia capitata						
Nuytsia floribunda					6	0.75
Orchidaceae sp (enamel orchid)						
Patersonia occidentalis				1		0.125
Pennisetum villosum*						
Pentaschistis thumbergii*						
Petrophile linearis	1	0.5			4	0.5
Philotheca spicata						
Phlebocarya ciliata						
Phyllangium paradoxum						
Pithocarpa pulchella						
Plathytheca galioides			3	0.75		
Poa porphyroclados						
Podotheca chrysantha				0.125		0.5
Podotheca gnaphalioides						
Regelia ciliata						
Rumex crispus		0.125				
Schoenus curvifolius						
Schoenus pedicellatus						
Scholtzia involucrata						
Sonchus sp *						
Stirlingia laterfolia						
Stylidium brunonianum	3	0.125			12	0.375
Stylidium junceum						
Stylidium macrocarpum						
Stylidium piliferum	4	0.125			3	0.125
Stylidium repens		2		3.25		3
Stylidium schoenoides						
Taraxacum officinale*						
Thysanotus multiflorus						
Thysanotus patersonii						
Thysanotus thyrsoideus						
Trachymene pilosa		0.875		0.625		0.5
Tricoryne elatior						
Ursinia anthemoides *		0.625		0.375		0.5
Verticordia drummondii						
Verticordia nitens	11	2.5				
Waitzia suaveolens		0.375		0.125		0.125
Xanthorrhoea gracilis						
Xanthorrhoea preissii	19	20	19		2	3
Xanthosia huegelii				9.75		
Unknown 1	29	4.5	12	1	12	2